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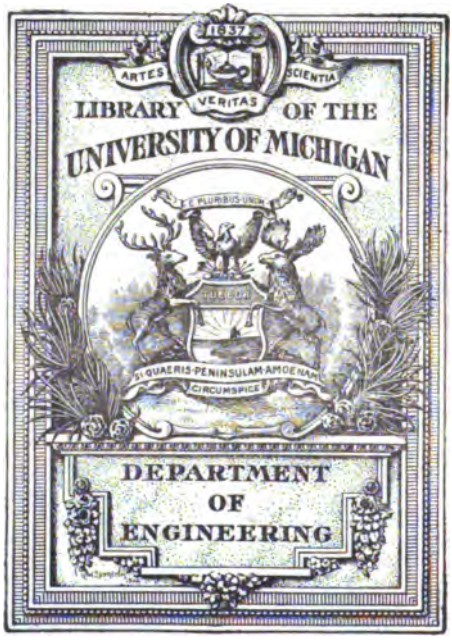

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MARINE BOILERS

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THEIR CONSTRUCTION AND WORKING, DEALING MORE ESPECIALLY WITH TUBULOUS BOILERS.

BY

L. E. BERTIN,

CHIEF CONSTRUCTOR OF THE FRENCH NAVY.

TRANSLATED AND EDITED BY

LESLIE S. ROBERTSON,

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WITH A PREFACE BY SIR WILLIAM WHITE, K.C.B., F.R.S.,

DIRECTOR OF NAVAL CONSTRUCTION TO THE ADMIRALTY,
AND ASSISTANT-CONTROLLER OF THE NAVY.

WITH UPWARDS OF 250 ILLUSTRATIONS.

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PREFACE.

By Sir WILLIAM H. WHITE, K.C.B., F.R.S.,

Director of Naval Construction,
And Assistant-Controller of the Navy.

At the request of both the Author and the Translator I have undertaken to introduce to English readers this version of a standard French work on Marine Boilers. It is a pleasant task, since the book is certain to receive a welcome from all who are interested in the production and use of steam-power.

Although M. Bertin is so well known, not merely in France but in all maritime countries, I may be permitted to indicate briefly what his claims are to deal with this important subject. He is one of the most eminent members of that distinguished body, the *Génie Maritime*. His career has embraced long service in the French Dockyards, at sea, and in the Ministry of Marine. He has been engaged for some years as principal technical adviser to the Japanese Ministry of Marine, under special permission of the French Government. Since his return from Japan he

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has occupied the important posts of Principal of the *Ecole d'application du Génie Maritime*, *Directeur du Matériel*, and *Chef du Service Technique* at the Ministry of Marine. The last-named Office he now occupies; and, under existing regulations, he is responsible to the Minister of Marine for the practicability and technical accuracy of the designs for all new French ships. As a matter of fact, M. Bertin is the responsible designer of the latest and swiftest cruisers now building in France. Consequently, no one is better placed for speaking authoritatively and with complete information respecting the most recent French practice in Marine Engineering and Boiler Construction.

The book originated in courses of lectures given to the students at the *Ecole d'application du Génie Maritime*. It is well known that the French system of education for these students embraces training in both Naval Architecture and Marine Engineering. With us, after a short preliminary training in common, the courses of study for the two branches diverge and become specialised. It is still true, however, that every competent Naval Architect must have an intimate acquaintance with Marine Engineering, and that every fully equipped Marine Engineer must be conversant with the principles of ship construction. M. Bertin has produced a book, which is of interest and value to both Marine Engineers and Naval

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Architects. The former will find ample information respecting the history, development, and details of construction of various types of Boilers. The Naval Architect will find, in addition, particulars such as are essential to the preparation of ship designs.

As compared with English text-books, perhaps the chief interest of this work will be found in sections dealing with tubulous Boilers. In the use of such Boilers for Marine purposes French engineers have shown remarkable courage and enterprise. The Mercantile Marine offers many examples of this fact; but it is in the French War Fleet that most has been done. In fact, the tubulous Boiler now reigns supreme from the torpedo-boats up to the largest cruisers and battleships. A change such as this, carried through in a comparatively short time, has necessarily involved much of an experimental nature. M. Bertin deals with the subject frankly and exhaustively. He traces the history of each type of Boiler, enumerates its advantages and its disadvantages, summarises its experience, and indicates the line of future progress.

All English Naval Architects and Marine Engineers are happy to acknowledge the lead which their French colleagues have taken in this matter, and the benefit which they have obtained from French experiment and experience with tubulous Boilers. This book presents the best summary yet available, from a French source, of what that experience has been.

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It is hardly necessary to add that in its arrangement, style, and terseness, the book is a worthy specimen of French method. In its English dress much information has been added of the latest French practice.

The work of translation has been admirably performed by Mr. Leslie Robertson, whose thorough acquaintance with Engineering in general, and with tubulous Boiler construction in particular, make him specially qualified for the work he has undertaken.

W. H. WHITE.

October, 1898.

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AUTHOR'S PREFACE.

WHEN the task of lecturing on "Boiler Construction" to the future engineers of the French Navy at the "Ecole du Génie Maritime," where the preliminary education is purely scientific, fell to my lot, I had had considerable experience in actual construction in many branches though none in lecturing. I was much more interested in the theory of ships and their construction than in the thorough study of the propelling machinery.

My treatise on "Marine Boilers" was undertaken somewhat unexpectedly, and was prepared for a very special audience. I was led to write it chiefly because I could not find in any of the many excellent existing text-books an account of the evolution that was then going on in boiler construction. I hope this may secure for me the indulgence of English specialists, and particularly of those from whom I have frequently had occasion to borrow information.

I took a deep interest in my task when once it was begun. I had always kept abreast of the boiler question, and had the pleasure of knowing intimately M. Sochet, M. du Temple, and M. Joessel, all of whom are now dead. My official duties have made me familiar with the efforts of M. Belleville, who worked with great perseverance for a long time before they were crowned with success. The fact that I was not an inventor myself placed me in a favourable position to form an impartial judgment on the various systems now in operation.

One all important condition was, however, lacking to me,

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viz., the time necessary for sustained and continuous work. I only lectured on the subject of Marine Boilers for one year, and the present work, which was published at the instigation of friends, would have been more complete if it had undergone a complete revision in a second course of lectures.

The present English edition, however, will not suffer from the precipitation that attended the publication of the original French text. The necessary work of revision has been carried through by Mr. Leslie S. Robertson with great ability, and with a carefulness which it was impossible for me to exercise; there is not a figure which has not been checked, nor a calculation which has not been verified. Mr. Robertson has been an invaluable collaborator. He has spent on the English translation probably more time and trouble than I devoted to the original French composition.

I offer my most cordial thanks to my learned friend, Sir William White, who has been kind enough to introduce my work to the British public. He knows that I entertain, in the highest degree, for all his works, the esteem which he has shown for mine, and he may perhaps suspect that, if I were of a jealous disposition, he would be the man of whom I should be most envious.

L. BERTIN.

PARIS,
October, 1898.

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EDITOR'S PREFACE.

M. BERTIN, Director of Naval Construction and Chef du Service Technique in the French Navy, is well known in this country as a prominent Member of the Institution of Naval Architects, to whose Transactions he has added many valuable contributions. An English edition of his recent work on 'Marine Boilers' is sure to meet with a favourable reception by all those interested in marine, and especially tubulous boilers.

The information and opinions published in the present work must carry additional weight from the fact that the Author, by virtue of his high official position, has the fullest and most recent information at his disposal. And further, the part played by the French as pioneers in the introduction of the tubulous boiler on a practical scale for naval purposes, lends particular interest to the chapters on the introduction and development of this class of boiler.

Much attention has been directed to the important question of coal consumption by the French, and the results of the trials contained in the following pages will be read with interest in view of the attention at this present moment being directed to this subject in our own Navy.

The French edition was the outcome of M. Bertin's lectures to his students at the "Ecole d'application du Génie Maritime," but it has been revised and added to so as to bring the subject-matter up to date. The particulars and the tables of weights of the Jeanne d'Arc and Château-Renault, now under

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construction, are particularly valuable on account of the size and importance of the installation. It also indicates an important departure from what has been up to this present time the usual practice of fitting vessels of this size with large tube boilers, such as the Belleville boiler.

In the preparation of the English edition I have adhered to the original text as far as possible, and have, after careful consideration, decided to maintain the numbers of the figures and paragraphs indentical with those of the French edition, in order to facilitate reference. In the English edition, where the ground has already been covered by other text-books, some of the original French illustrations have been omitted and the subject-matter in places compressed, while in other places of special interest it has been extended, added to, and brought up to date. The value of the work has also been further enhanced by the addition to the English edition of a very complete index, which should materially add to the value of the work for purposes of reference.

The conversion of the French figures into their corresponding British units has entailed a very large amount of work, but it has enabled me to eliminate many of the little inaccuracies occurring in the original French edition, which were no doubt due to the heavy calls upon M. Bertin's time when preparing his work for the press.

The term *Chaudière à tubes directs* has throughout been rendered *direct tube boiler* or Admiralty type boiler in contra-distinction to *Chaudière à retour de flammes* or *return tube boiler*.

It must be borne in mind that the opinions and facts advanced are those given by the Author, and that they refer in nearly all cases to French practice, which materially differs from our own.

I beg to tender my thanks to the various firms who have placed valuable information at my disposal, to Mr. Frankish of Messrs. John I. Thornycroft & Co., for his assistance, and especially to my assistant, Mr. Charles Dresser, for the great

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care and attention he has given to the preparation of the present edition.

I regret that the many calls upon my time have delayed the earlier appearance of this book; the delay has, however, had one advantage, namely, that of enabling me to include some of the most recent results which do not appear in the original French edition.

In conclusion, I beg to tender my best thanks to Sir William White, K.C.B., for the preface that he has been good enough to write for the English edition of his friend M. Bertin's work on 'Marine Boilers.'

LESLIE S. ROBERTSON.

WESTMINSTER,
October, 1898.

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MARINE BOILERS.

PART I.

CHAPTER I.

THE PRINCIPAL LAWS UNDERLYING STEAM NAVIGATION.

Notation Employed.

A. Weight of coal carried, in tons.

B^2. Immersed midship section in square feet.

C. Coal consumption per horse-power-hour in lbs.

D. Radius of action, in knots, without deducting the coal used for the auxiliary engines from the total amount carried.

D'. Radius of action, in knots, deducting coal required for auxiliaries.

F. Indicated horse-power exerted on the pistons.

F_1. Brake horse-power.

I. Coefficient $\frac{M^3}{CV^2}$ for multiplying the coefficient N by in order to obtain the radius of action D.

M. $V = M \sqrt[3]{\frac{F}{B}}$

M_1. $V = M_1 \sqrt[3]{\frac{F}{P_1}}$

Coefficients of performance taken from the formulæ

N. Coefficient of radius of action, neglecting consumption of auxiliary machinery.

N'. Coefficient of radius of action, including consumption of auxiliary machinery.

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P. Displacement in tons.

Q. Total weight in tons of propelling machinery, including coal.

R. Resistance offered by the water to motion of the ship.

V. Speed of ship in knots.

λ. Ratio of corresponding dimensions of two similar ships or of those of a ship to those of a model.

c. Stroke of piston in feet.

d. Diameter of piston in inches.

n. Revolutions of engine per minute.

p. Total mean pressure of steam on the pistons, as shown by the indicator diagrams, in lbs. per square inch.

m. Weight per horse-power of engine in tons.

q. Consumption of the auxiliary machinery per twenty-four hours.

S, S_1. Constants in the "law of similarity." *

u. Mechanical efficiency of engine (ratio of brake horse-power F_1 to indicated horse-power F).

u_1. Efficiency of propeller (ratio of useful work performed by the screw to the brake horse-power F_1).

1. *Adoption of Steam for Marine Purposes.*—Steamships have entirely taken the place of the old sailing vessels in the navy; but in the mercantile marine this substitution is not quite so complete. With the quick transits and low freights now in vogue, the sailing vessel can no longer hold her own against her steam rival, except under certain conditions.

Sails, retained for a long time as an auxiliary means of propulsion, are now disappearing from all steamships, since the adoption of multiple screws driven by independent engines. In the case of warships they have almost entirely disappeared.

The results of the adoption of steam on board ship, looked at from a general point of view, are a great increase in speed and greater regularity of service.

* See 'Manual of Naval Architecture,' by Sir W. H. White, page 474, last line but one.

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§ 1. SPEED.

2. *Speed of Steamships.*—Speed in a sailing ship depends so largely upon the direction and force of the wind that it is extremely difficult to form an estimate of the probable length of a voyage based on a knowledge of the speed of the ship itself under favourable circumstances.

Thirty or forty years ago four knots was considered a good average speed for a sailing ship making a long voyage. The clippers specially built for the China trade, however, frequently made an average of six knots; but this was considered exceptionally good.

The steamship entered upon its career with the same speed as the China clipper ships; the *Sphinx*, making six knots between Algiers and Toulon in 1830, marked the first step.

In the present day, cargo-carrying steamers have speeds of at least ten knots, while the Transatlantic liners attain mean speeds of twenty-one knots under favourable circumstances. Large warships have speeds equal to the Transatlantic liners, but their engines rarely have sufficient endurance for a run of over three thousand miles at a speed of twenty-one knots. Torpedo-boats, and other boats built for special purposes, with a very small radius of action, are not included here, reference being made solely to ships having a considerable radius of action.

The improvement in speed, which goes on from day to day, affects the merchant service as well as the navy, for this reason, that the safety of the former in time of war depends on their being faster than the latter.

Speed is a costly quality; it is generally regulated in the merchant service by the competition between shipowners, and in the navy by the rivalry existing between the navies of different maritime powers.

3. *Coefficient of Performance—its two Forms.*—The elementary formulæ, which are used in practice to determine the

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speed of a ship as a function of the engine-power, are the following :—

Let F be the gross work done by the steam upon the pistons, proportional to the mean pressure on the piston $\frac{\pi}{4} d^2 p$, and to the space passed over in one minute $2cn$: the work absorbed in propelling the ship, calling u the efficiency of the engine, and u_1 the efficiency of the screw, equals:

$$u\, u_1\, \mathrm{F}.$$

On the other hand, if R is the ship's resistance, and V the speed of the ship, the total work done in overcoming the resistance to motion will be

$$\mathrm{R\ V}.$$

Equating these two expressions we get—

$$\mathrm{R\ V} = u\, u_1\, \mathrm{F}. \tag{1}$$

For any given vessel moving with a variable velocity, we may assume that the following law holds approximately:—

$$\mathrm{R} = \mathrm{K\ V}^2. \tag{2}$$

Now for boats of similar form but of different dimensions, the law of similarity shows that when V^2 is proportional to λ R is proportional to the cube of λ; the following relations then hold good:—

$$\mathrm{V}^2 = s\, \lambda$$

$$\mathrm{R} = s_1\, \lambda^3$$

from which we obtain—

$$\frac{\mathrm{R}}{\mathrm{V}^2} = \frac{s_1}{s}\, \lambda^2$$

$$\mathrm{R} = \frac{s_1}{s}\, \lambda^2\, \mathrm{V}^2$$

The coefficient K, which is independent of V, should then be proportional to λ^2: this can be expressed thus:—

$$\mathrm{K} = k\, \mathrm{B}^2 \tag{3}$$

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B^2 being the immersed midship section, it can also be written:—

$$K = k_1 P^{\frac{2}{3}} \tag{3a}$$

in terms of the displacement P. From these we get the two equations:—

$$K B^2 V^3 = u u_1 F \tag{4}$$

$$k_1 P^{\frac{2}{3}} V^3 = u u_1 F. \tag{4a}$$

From these we obtain the two following expressions for V:—

$$V = \sqrt[3]{\frac{u u_1}{k}} \sqrt[3]{\frac{F}{B^2}} \tag{5}$$

$$V = \sqrt[3]{\frac{u u_1}{k_1}} \sqrt[3]{\frac{F}{P^{\frac{2}{3}}}} \tag{5a}$$

The gross work F is known; the speed V is measured on the trials; we therefore obtain a value for a coefficient, which may be written in two ways:—

$$M = \sqrt[3]{\frac{u u_1}{k}}$$

$$M_1 = \sqrt[3]{\frac{u u_1}{k_1}}$$

and this coefficient is called the "coefficient of performance" of the ship,* M being known as the "midship-section coefficient" and M_1 as the "displacement coefficient."

We have no means of determining the value of the factors u, u_1, k, or k_1, which we have only introduced to explain the coefficient of performance.

The values of M and M_1 vary for the same ship, because K in formula (2) changes with the velocity V, and u and u_1 vary with the revolutions of the engines.

On the other hand, for boats of similar form but of different dimensions, experiment proves that, for speeds proportional to $\sqrt{\lambda}$, the actual resistance, compared with that given by the law

* The values given for the coefficients of performance are the cube roots of the "Admiralty coefficients." See 'Manual of Naval Architecture,' by Sir W. H. White, page 566.

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of similarity, is greater for small boats and less for large ones. Besides, no ships are exactly alike, and their speeds, V, do not in the least satisfy the conditions required by the law of similarity; so that for these reasons, in expressing the speed, V, by one or other of the formulæ,

$$V = M \sqrt[3]{\frac{F}{B^2}} \tag{6}$$

$$V = M_1 \sqrt[3]{\frac{F}{Pi}} \tag{6a}$$

we must look upon M and M_1 as variable and purely empirical coefficients. When designing a new boat their values can only be determined with any exactness if the results of trials, made upon a ship nearly identical in form, at similar rates of speed, and under precisely similar conditions, are known. Some experimenters say the depth of water must be the same in both cases.

The determination of the speed, as a function of the horse-power, requires, as has been seen, a knowledge of a great number of values of M and M_1, or rather of a great number of curves of M and M_1, plotted as a function of the speed. The determination of the speed of a boat that has to be built to a hitherto untried design, or is intended to attain speeds beyond those already realised, can be considerably facilitated by making experiments upon a model under the conditions imposed by the law of similarity. The interpretation, however, of the results obtained by these experiments, requires the greatest care and attention.

The Table on page 7 gives values of M and M_1 for some recently-constructed ships for the French Navy. It will be noticed that these values sensibly decrease on passing from the larger ships to the smaller, the resistance then becoming proportional to a power of λ, rather less than the square.

The experiments made on the *Forban* have led M. Normand to conclude that the coefficients M and M_1 have a minimum value at a certain speed for each ship; after reaching this they increase indefinitely. The speed to which this minimum value

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corresponds, and which for torpedo-boats of one hundred and twenty-three tons' displacement is about twenty knots, would be approximately proportional to the sixth root of the displacement, that is to say, to $\sqrt{\lambda}$, if the law followed by these small boats held universally.

The formula (6*a*) leads to a curious result, if we assume M constant, and further, that the weight assigned to propelling machinery is a constant fraction of the displacement P.

Name of Ship.	Speed in Knots. V	Horse-Power. F	Coefficients of Performance.		Displacement on Trial.
			M	M_1	Tons.
Magenta	16·21	10,566	8·517	5·812	10,755
Terrible (French Navy) .	14·51	5,293	9·012	6·048	7,505
Jemmapes	15·68	8,998	7·848	5·291	6,442
Cocyte	11·27	1,421	7·688	5·215	1,671
Mitraille	10·34	736	7·772	5·404	1,078
Dupuy-de-Lôme . . .	19·73	13,015	8·222	5·799	6,008
Cécile	19·44	10,727	8·193	5·955	5,414
Sfax	16·75	6,968	8·215	5·679	4,470
Friant	18·89	9,316	7·994	5·566	3,679
Troude	20·91	6,350	7·899	6·005	1,845
Condor (French Navy) .	17·51	3,291	8·102	5·728	1,232
Levrier	18·38	2,197	7·000	5·491	448·3
Bombe	19·20	1,944	6·830	5·535	317·8
Forban	31·03	4,121	6·981	5·669	126·3
Chevalier	26·72	2,918	6·590	5·329	111·5

The weight of the engines is, according to the law of similarity, proportional to the cube of the linear dimensions. The power, which is given by the expression $F = 2\,\frac{\frac{\pi}{4}d^2\,c\,n\,p}{33{,}000}$ is only proportional to the square of the dimensions (d^2) when the mean piston speed $c\,n$ and the steam pressure p are alike in both cases. The power of the engines is then theoretically proportional to the two-thirds power of their weight Then, according to our assumption, the ratio F to $p^{\frac{1}{2}}$ is constant, and the speed V is therefore constant in accordance with formulæ (6) and (6*a*) whatever may be the size of the boat. There is, therefore,

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nothing contrary to first principles in the very great speeds that have been attained on small boats.

It was assumed above that the mean piston speed $c\,n$ was constant; this hypothesis does not hold for the case of complete similarity between two sets of propelling machinery, including engines and screw. The exact relation would then be $c\,n = \sqrt{s}\sqrt{\lambda}$ for the same steam pressure; but as a matter of fact, the engines of these small boats have a higher speed of revolution than the law of similarity would assign to them, and the equation $c\,n$ = constant, is more nearly true than $c\,n = \sqrt{s}\sqrt{\lambda}$.

§ 2. RADIUS OF ACTION.

4. *Calculation for Determining the Radius of Action.*—The greatest distance that a ship can steam—a property as important as the speed—depends upon the amount of coal carried and the speed at which the distance has to be covered. Let C be the consumption of coal per horse-power per hour; then for a given power F, the consumption equals F C; if V be the corresponding speed, the consumption per knot is—

$$\frac{F\,C}{V};$$

for a distance D, the coal burnt will be—

$$\frac{F\,C}{V} \times D,$$

which must be equal to the weight of coal carried in the bunkers A, and the following equation is obtained:—

$$D = A \times \frac{V}{F\,C}. \tag{7}$$

Taking the ratio V to F from the equation (6*a*) in order to eliminate F we get

$$\frac{V}{F} = M_1^3 \frac{1}{P^{\frac{1}{3}}} \frac{1}{V^2} \tag{8}$$

from which equation it follows that, for a given ship, if A

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and C be constant, the radius of action D given by the formula

$$D = \frac{M_1^3}{C} \times \frac{1}{V^2} \times \frac{A}{P^i} \tag{9}$$

is inversely proportional to the square of the speed.

If two exactly similar ships, but of different rates of speed, be compared, fitted with engines giving a maximum efficiency at the required speed, we shall find that A decreases more slowly than indicated by the law of the squares.

In reality, if the maximum power is decreased from F to F' in direct proportion with the speed, and if the total weight of machinery, coal, &c., be constant, we shall have—

$$A + m\,F = Q \tag{10}$$

$$A' + m\,F' = Q \tag{10a}$$

from which we get

$$A' = A + m\,(F - F').$$

If we assume that the weight of coal A is equal to the weight of the propelling machinery m F, as is often the case, and if the speed of the second ship is half that of the first, which makes $F' = \frac{F}{8}$, we obtain

$$A' = A + A\,(1 - (\tfrac{1}{2})^3); \tag{11}$$

and A' is then nearly double A. Under these conditions the radius of action when steaming at full speed, instead of being multiplied by four, is multiplied by eight. With the same speed the radius of action of the second ship is nearly double that of the first.

As the speed at which a ship can traverse a certain distance depends upon the amount of coal carried, we arrive at this apparently paradoxical conclusion, namely, that for a constant weight of propelling machinery, the speed, within the radius of action, is as much greater as the maximum power of the engine is less.

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Now let us consider the case of ships of different dimensions moving at the same rate of speed, and let us assume that for all of them the amount of coal carried A is the same fraction o of the displacement P; replacing A by oP in equation (9), the value of D can then be written :—

$$D = \frac{o\, M_1^3}{C\, V^2} P^{\frac{1}{3}}. \tag{12}$$

Thus, if, on dividing up the various weights composing the displacement, we find that the total weight of coal carried is a constant fraction of the total displacement, the radius of action increases as the cube root of the displacement.

While high speeds do not necessitate a large displacement, a large radius of action does do so.

5. *Coefficient of Radius of Action.*—Replacing o by its value $\frac{A}{P}$ in equation (12), we obtain :—

$$D = \frac{M_1^3}{C\, V^2} \frac{A}{P^{\frac{1}{3}}}. \tag{13}$$

The radius of action of a ship, assuming that V is constant, and that the variations of M_1 and C are negligible, is proportional to the ratio between the total amount of coal carried A and the two-thirds power of the displacement,

$$N = \frac{A}{P^{\frac{1}{3}}}. \tag{14}$$

This quantity N is called the "coefficient of radius of action."

For warships which steam at greatly varying speed it has been the custom for a long time in the French Navy to calculate the radius of action at a speed of ten knots, neglecting the consumption of coal required by the auxiliaries; under these conditions, assuming $M_1 = 5{\cdot}75$ and $C = 1{\cdot}78$ lbs., we have, taking the ton as unity :—

$$\frac{M_1^3}{C\, V^2} = 2016.$$

$$D = 2016\ N. \tag{15}$$

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Assigning to N the three values, 0·75 – 1·50 – 3·0, which are very nearly those for coast-defence vessels, first-class battleships, and cruisers, we obtain for D the three following values, 1,512 miles, 3,024 miles, and 6,048 miles.

The special purpose for which a warship has been designed, is therefore more clearly shown by the coefficient N than by any other data.

Passenger boats carry a supply of coal proportional to the length of their voyage and their actual speed, but greatly exceeding the amount given by formula (13), so as to be prepared for any unfavourable weather they may encounter on their passage.

For short voyages, for instance between Algiers and Toulon, double the theoretical amount of coal is carried. For long voyages the excess is not so great; thus a Transatlantic liner, which burns in fine weather 1,700 to 1,800 tons of coal during the run from Havre to New York, carries in her bunkers 2,300 tons, which is about 33 per cent. in excess of the estimated consumption. Ships have been known to run short of coal as the result of meeting with persistent bad weather; as a case in point, a passenger vessel running from Colombo to Aden may be cited which was caught in a north-west monsoon, and, after having accomplished more than two-thirds of the voyage, had to return with the help of her sails to Colombo in order to coal. This example shows that the adoption of multiple screws cannot be regarded as a complete substitute for sails, unless care is taken to increase the supply of coal carried at the same time.

In the French Navy 10 per cent. more coal is allowed in commission than was burnt during the trials. This increase compensates for the difference in the quality of the coal, and in the skill of the stokers, but does not take into account the condition of the sea during a voyage. The effect of the state of the sea upon steam navigation will be returned to later on.

6. *Consumption of Coal by Auxiliary Machinery.*—The values of the coefficient N, which appears in formula (15), will be given for some of the boats already considered with

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regard to M and M_1; account has been taken in the calculation of N of the true values of M_1, of C, and, approximately, of the consumption of the auxiliaries. This last correction is important, for upon some battleships the auxiliary engines consume not less than 4½ to 5½ tons of coal per day. It is made in the following manner:—

Let q be the consumption of coal of the auxiliaries in tons per twenty-four hours; the ship being continually in motion, the consumption per hour is one-twenty-fourth of this, which brings the consumption per mile run to—

$$\frac{q}{24\ V}$$

and the consumption for a distance D is—

$$\frac{q\ D}{24\ V}$$

Now

$$D = 2016\ N \tag{15}$$

and the coal available for propulsion A is then reduced to—

$$A' = A - q\frac{D}{24\ V} = A - q\frac{2016\ N}{24\ V} = A - 84\,q\frac{N}{V} \tag{16}$$

The value of N is consequently diminished and becomes N':

$$N' = \frac{A'}{P^{\frac{2}{3}}} = N - 84\,\frac{q}{P}\frac{N\ P^{\frac{1}{3}}}{V} \tag{17}$$

The consumption q is nearly proportional to the displacement, so that we can write—

$$\frac{q}{P} = 0{\cdot}0005 \tag{18}$$

which assumes a consumption of 1 ton of coal per day for a cruiser of 2,000 tons and 6 tons for a battleship of 12,000 tons.

Making at the same time V = 10 knots, we obtain—

$$N' = N - 0{\cdot}0042\ N\ P^{\frac{1}{3}} = N\ (1 - 0{\cdot}0042\ P^{\frac{1}{3}}) \tag{19}$$

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The coefficient of radius of action falls more rapidly the bigger the ship; it falls to 0·925 N for a ship of 11,600 tons displacement.

7. *Most Economical Speed.—Actual Radius of Action.*—The total consumption per mile, including that of the auxiliaries, is given by—

$$(20)\quad \frac{F\,C + \frac{q}{24}}{V} = \frac{F\,C}{V} + \frac{q}{24\,V} = \frac{P^{\frac{2}{3}}\,V^2}{M_1^3}\,C + \frac{q}{24\,V}$$

This consumption, by reason of the form of its two terms, will have a minimum value. The corresponding value of V, C and M_1 being constants, will be determined by the equation—

$$(21)\quad 2\,\frac{C\,P^{\frac{2}{3}}}{M_1^3}\,V - \frac{q}{24\,V^2} = 0$$

from which, making $q = 0{\cdot}0005\ P$, $M_1 = 5{\cdot}755$ and $C = 1{\cdot}78$, we obtain, expressing C as a decimal of a ton—

$$V = \sqrt[3]{\frac{q\,M_1^3}{48\,C\,P^{\frac{2}{3}}}} = \sqrt[3]{\frac{M_1^3\,P^{\frac{2}{3}}}{96000\,C}} = 1{\cdot}357\sqrt[9]{P}$$

In reality the most economical speed depends chiefly upon the value of C, which is greatly increased for small values of V; and its determination requires the tracing of two separate curves, one for the consumption per mile of the main engines, and the other for that of the auxiliary machinery (equation 20),

$$(22)\quad y = \frac{P^{\frac{2}{3}}\,V^2}{M_1^3}\,C$$

$$(23)\quad y_2 = \frac{q}{24\,V}$$

the second of which is a hyperbola.

With the sum of the ordinates y and y_2 a resultant curve can then be drawn and the horizontal tangent found.

In getting out the design of warships a distinction is made between the amount of coal required for the auxiliaries and that used in propelling the ship. In practice this separation

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cannot be made, since the ratio between the two consumptions varies with the speed on a voyage and the length of time the vessel is at anchor. During some commissions the consumption of the auxiliaries may reach 20 or even 30 per cent. of the total supply of coal on account of the amount consumed while at anchor.

D′ the radius of action at a speed of 10 knots, taking into account the consumption of the auxiliaries, has been calculated from formula (17) for the ships in the following Table.

Name of Ship.	Data.				Calculated Coefficients.					
	P	A	M_1	C	I	N	IN = D	N′	IN′ = D′	F
	Tons.	Tons.		lbs.						
Magenta . .	10,678	605·3	6·314	2·07	2717	1·248	3391	1·113	3024	1927
Terrible (Fr. Navy) . .	7,490	393·6	6·767	3·53	1961	1·027	2014	0·942	1847	1234
Indomptable .	7,465	393·6	6·767	3·58	1932	1·030	1990	0·944	1824	1234
Jemmapes .	6,487	295·2	5·829	1·52	2917	0·848	2474	0·781	2278	1757
Cocyte . .	1,687	70·9	5·551	2·09	1822	0·500	911	0·475	865	829
Dupuy-de-Lôme . .	6,477	885·8	5·925	1·67	2781	2·548	7085	2·346	6508	1670
Isly . . .	4,404	571·8	6·061	1·36	3643	2·127	7748	1·979	7190	1204
Friant . .	3,679	575·7	5·755	2·06	2061	2·415	4978	2·216	4567	1251
Lalande . .	1,895	283·4	5·802	2·05	2126	1·850	3933	1·753	3727	785
Lævrier . .	496·4	93·5	4·846	1·65	1542	1·491	2299	1·441	2222	551
Bombe (at 14 knots) . .	413·0	103·3	5·328	2·08	826	1·862	1538	1·803	1271	1000
Forban (at 14 knots) . .	149·7	17·7	5·598	0·85	2340	0·628	1470	0·614	1437	441
Chevalier . .	132·1	15·7	4·979	0·805	3439	0·618	2157	0·604	2077	210

The displacements given in this Table are taken from the finished designs of the boats prior to construction, and this explains why they do not quite agree with the figures in the Table on page 7, which was compiled from the figures obtained on the official trials. For the estimated displacement of 6,200 tons the coal supply A of the *Dupuy-de-Lôme* is only 609 tons, corresponding to a value of D′ = 4,500; a similar remark applies to several of the ships referred to in the Table, the coal supply given being in excess of the actual amount carried.

In order to show the practical application of formula (15) to different types of ships in the French Navy, a Table is inserted giving the distance in sea miles between two of the principal

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naval ports of France and the foreign stations usually visited by French warships. The speed assumed is 10 knots.

From Cherbourg to—	Miles.	*From Toulon to—*	Miles.
Brest	189	Funchal	1316
Dunkerque	161	Santa Cruz	1418
Wilhelmshaven	478	St. Louis	2159
Hamburg	524	Halifax	3375
Christiania	760	New York	3384
Kiel	917	Fort de France	3950
Dantzig	1118	Rio Janeiro	5012
Riga	1303	Cape Town	5913
Cronstadt	1549	Buenos Ayres	6012
Funchal	1282	Alexandria	1323
Santa Cruz	1498	Massowah	2535
St. Louis	2271	Colombo	4924
Halifax	2524	St. Pierre	5282
New York	3066	Pondicherry	5530
Fort de France	3950	Saigon	7150
Rio de Janeiro	5012	Hong-Kong	7885
Cape Town	5913	Yokohama	9858
Buenos Ayres	6012	Sydney	9746

From Toulon to San Francisco	13,468	miles by the	Cape of Good Hope.
	13,231	„ „	Straits of Magellan.
From Brest to Noumea	12,759	„ „	Cape of Good Hope.
From Dunkerque to Foo-Chow	13,347	„	

These Tables enable the radius of action of a fleet to be easily determined.

It will readily be seen that ironclads cannot make the return voyage to Alexandria, coast-defence vessels one to Kiel, and cruisers one to New York or Halifax, even if we assume that the ship travels direct there and back, without carrying out any military operations or manœuvres. It is for this reason that sails have been preserved as an auxiliary source of motion upon most of our battleships, and it explains why, even upon passenger ships, masts are still carried, though they are practically of little value in time of peace owing to the facilities for re-coaling.

Sails, in comparison with steam, form a very light source of motive power. Their total weight on a large ship scarcely ever exceeds 10·2 lbs. per square foot of sail area, or 307 lbs. per

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square foot of midship section; this is equivalent to an engine of 0·32 horse-power per square foot of midship section, which would formerly have weighed 0·49 ton without the coal, to which must be added 0·49 ton per 1,000 sea miles run at 6 knots. Under these conditions sails have the superiority over steam for distances of over 2,000 sea miles, and they are still retained for merchant ships going long voyages.

8. *Curves and Tables of Horse-power, Consumption, etc.*—The application of algebraical formulæ such as (6) and (13) to the calculation of the general problems in ship propulsion is a very useful method of arriving at an approximate solution of the questions involved. As soon, however, as we consider the case of a ship moving at a variable rate of speed, we can no longer assume that the coefficient of performance M_1, the consumption per horse-power C, and consequently the coefficient of radius of action N, are constants. We must therefore have recourse to curves giving the actual conditions of working at various speeds.

In practice these curves are supplied with the drawings of each boat. Taking the revolutions as the abscissæ, speed, horse-power, coal per hour and coal per horse-power hour, are plotted as the ordinates. Four curves are thus obtained from which the curves giving the coal burnt per mile and the coefficients of performance and radius of action are easily deduced.

The following Table gives the results obtained from the coast-defence vessel *Indomptable* which have served as a basis for the design of other ships.

Revolutions per Sec.	Speed in Knots. V	Horse-Power. F	Consumption of Coal.	
			Per Hour.	Per Horse-Power-Hour. C
			lbs.	lbs.
30	5·51	276	1270	4·6
40	7·41	561	2215	3·95
50	9·12	1034	3472	3·36
60	10·92	1800	5173	2·87
70	12·58	2985	7374	2·47
80	14·05	4721	10,570	2·24
90	14·96	7067	19,610	2·77

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The readings in this Table lead to the two following results.

In the first place, the consumption of coal per horse-power, which varies about a third for speeds between 10 and 15 knots, is double at 5 knots what it is at 14 knots. The formulæ for the radius of action are therefore only applicable to slow speeds when giving to C values that have been determined by actual experiment.

In the second place, the speed V is practically proportional to the revolutions n; or, in other words, the forward movement of the ship for each revolution of the screw is constant whatever be the speed. This last remark is specially important, as the approximate rule that it enunciates is universal and holds for all ships at any rate of speed, the assumption being made, of course, that the sea is calm. On a rough sea the advance of the ship per turn of the screw diminishes considerably. This is the reverse of what takes place with a paddle-wheel, where it is always fairly constant.

The preceding rule can be expressed under another form. The speed V being proportional to n, and also proportional to the cube root of F, equation (6), the horse-power F is proportional to n^3. But, on the other hand, the horse-power F is proportional to the product $n\,p$, of the revolutions n and the mean pressure on the pistons. It follows at once from this that the square of the revolutions of the engine varies as the pressure p.

This law, which can be expressed thus—

$$\frac{n^2}{p} = \text{constant},$$

is of a more general character than that relating to the constant forward motion of the ship per revolution, as it is independent of the condition of the sea; when the ship loses speed the screws continue to revolve on account of the pressure p on the pistons very much as they would do if the sea were calm.

The coefficient of performance M_1 of a screw steamer decreases more rapidly from the effect of a heavy sea than does that of a paddle steamer, whose engines are not so liable to race, and the consumption of coal per mile run is greater for bad

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weather. This difference, which is of little real importance, was at one time brought forward as a strong point in their favour by the advocates of the slower paddle boats and with good effect.

The Table showing the results obtained from the *Indomptable* can easily be completed by the addition of the consumption per mile, the radii of action being calculated on the assumption that out of a total weight of 394 tons, 354 tons are available for the main engines, and by the addition of the coefficients of performance M and M_1 calculated respectively from the values of B^2 and P during the trials.

We then obtain the following Table:—

Revolutions per Sec. n	Consumption of Coal per Mile.	Radius of Action. D	Coefficients of Performance.	
			M	M_1
	lbs.	Miles.		
30	230·6	3487	9·150	6·132
40	298·9	2690	9·704	6·508
50	380·7	2112	9·746	6·535
60	473·5	1697	9·692	6·500
70	586·1	1371	9·442	6·331
80	752·2	1069	9·052	6·069
90	1310·5	613	8·431	5·654

§ 3. REGULARITY OF SERVICE.

9. *Effect of Pitching upon Speed.*—After the discussion of the question of speed and the radius of action, it may not be out of place to say a few words in regard to regularity of service, which was one of the greatest advances made in navigation due to the substitution of the steamship for the sailing vessel.

This regularity of service is particularly noticeable in the large passenger steamers of 10,000 to 18,000 tons displacement, which, standing as they do high out of the water, have everything arranged so as to ensure their making a quick passage in all weathers. It is also sufficient on large cargo steamers to compensate for the increase of their freight charges over those of sailing ships, but upon men-of-war the size of the

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ship and the particular shape or form imposed by the purpose for which the ship was built, make good behaviour in all weather of secondary importance.

Ships must satisfy two conditions in order to preserve their speed during rough weather. In the first place, their bows must be high and fine in order to prevent the heaping up or the shipping of too much water. In rough weather it is to be expected that at each dip a few tons of water will be taken on board, but this will easily be run off through the scuppers. In the second place, it is important to have a considerable draught of water at the stern in order to ensure a good immersion for the screw; this is absolutely necessary.

Large cruisers, that is to say those of from 8,000 to 14,000 tons have a regularity equal to liners. At about 6,000 tons the state of the sea has an appreciable effect. In order to be certain of an average speed of 12 knots in all weathers a displacement of not less than 3,000 tons is needed. Below 1,500 tons a ship can no longer be absolutely relied upon for scouting purposes. The whole of the long series of catchers and torpedo-boat destroyers can only be used with advantage in fine weather.

It would be interesting to know the number of days during the year in which the operations of any particular type of war-ship have been interfered with or hindered by the state of the sea; unfortunately no such data are obtainable.

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CHAPTER II.

SHORT DESCRIPTION OF VARIOUS TYPES OF BOILERS.

10. *General Considerations.*—The engine on board ship is often subjected, as a whole, as well as in detail, to severe strains.

The weight being limited to a given fraction of the displacement, lightness assumes an importance quite unknown in land engines. The maximum power that can be obtained from a given weight varies inversely as the weight of the machinery per horse-power; hence the great importance of this factor on the general value of the vessel. Further, economy in coal consumption on board ship is not merely a question of so much money saved, it is of much greater importance than that; it means a greater steaming distance with a given coal capacity, or a reduction of bunker capacity, which again in its turn means increased freight earning capacity, or increased armaments, as the case may be.

Lightness in boilers is primarily obtained by a reduction in the weight of water and the adoption of forced draught, although the reduction of weight realisable by attention to the smaller details must not be lost sight of. Forced draught has but little *raison d'être* on land, but is becoming more and more extensively used on board. It is possible to double, or even quadruple for a short time, the power of a boiler by means of forced draught, and the high speeds obtained, in the first instance on board torpedo-boats, and subsequently on board larger boats, is largely due to the application of forced draught.

The search for lighter engines led to the adoption of higher pressures, but in this case the advantages must be viewed in

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relation to the weight of machinery and coal as a whole, and not in relation to the boilers alone, as the weight of the actual boilers increases with the pressure.

Over and above the question of lightness, the space available on board for boilers is often very limited. They must be capable of being shipped on board without necessitating hatchways of excessive dimensions. They must be durable, as simple as possible, and capable in all cases of steaming long distances without undergoing repairs or the daily inspection required by locomotive boilers. Inspection ought to be possible entirely from the front of the boiler, which is generally the only side of the boiler at all easily accessible, and what small repairs may happen to be necessary should be able to be carried out with the means usually available on board ship.

Marine boilers are exposed, especially during manœuvres, to sudden changes in the rate of working, which often give rise to straining, and severely tax the elastic properties of the boiler.

With so many conditions to be fulfilled, it is not astonishing that the ideal boiler has not as yet been discovered.

The arrangement of the boiler on board has to be carefully thought out and considered, allowance being made for the protection of the neighbouring parts of the vessel from heat, ensuring a sufficient supply of air to the furnaces, and facilitating a sufficiently rapid supply of coal to the stokehold.

There are other details, such as getting rid of the ashes, which, though insignificant on land, assume considerable importance on board ship. These are more properly questions of ship construction, and we will content ourselves by merely calling attention to them in passing.

§ 1. CLASSIFICATION OF BOILERS.

11. *Flue Boilers.*—For a long time marine boilers belonged to the class known as internal flue or internal combustion boilers, of which there have been many varieties since the Cornouailles boiler, which is the oldest type of all. This type of boiler, which possesses advantages from the point of view of

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economy in combustion, was specially applicable to wooden vessels on account of its enhanced security against fire. It is

Vertical section on *yy*.

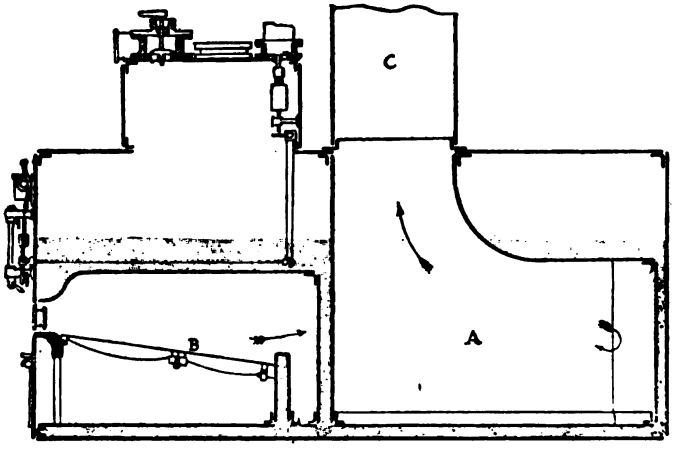

Fig. 4.

Half elevation and half section on *xx*.

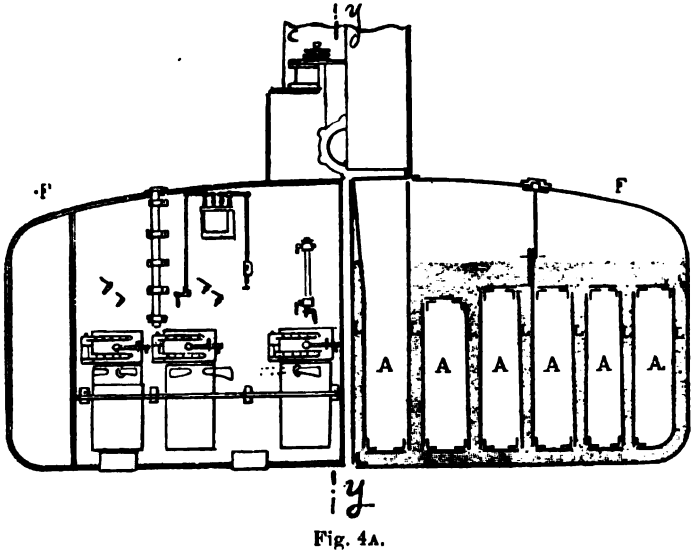

Fig. 4A.

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Half plan. Half section at grade level.

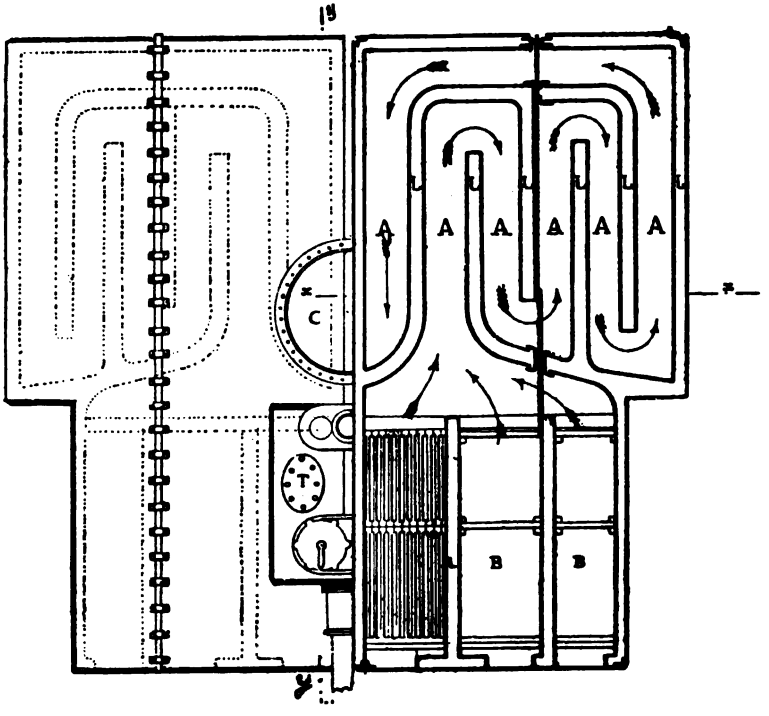

Fig. 4B.

A. Flame passages. B. Grate. C. Funnel.
LL. Water Spaces. T. Manhole.

characterised by the presence on all its sides of water spaces completely enveloping the furnaces and flame passages.

The earlier models, with the low boiler pressures then in vogue, were simple boxes of a parallelopiped form, where the flames circulated through large square passages with flat sides entirely immersed in the water, the top part of the boiler forming the steam space. Figs. 4, 4A, 4B.

12. *Tubular Boilers—Box Type.*—The first marked progress made in boiler construction consisted in the introduction of tubes of small diameters, dividing up the hot gases and increasing the heating surface.

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BOX TYPE OF BOILER
(1858–1870).

Scale—2 cm. = 1 mètre = $\frac{1}{50}$.

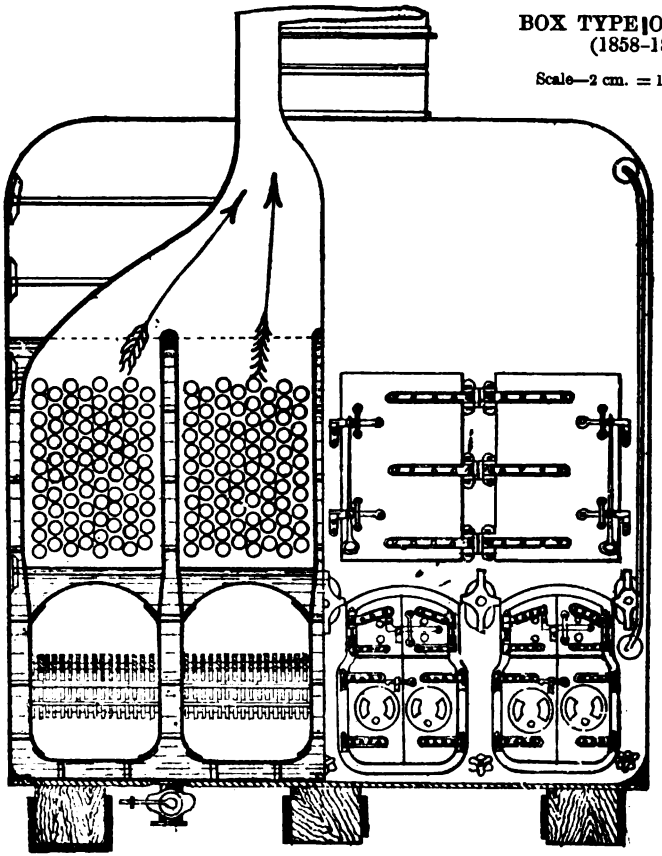

Fig. 5.

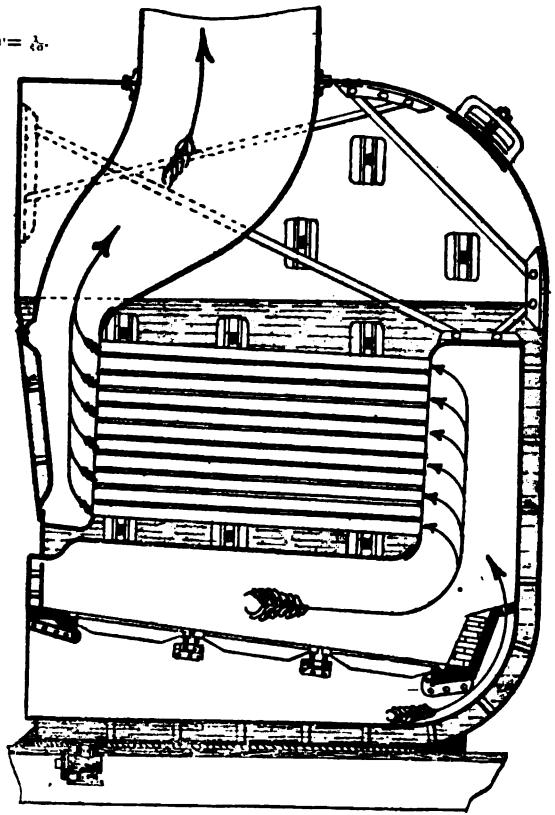

Fig. 5A.

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The box-shaped passages were replaced by a nest of tubes surrounded by water, through which the hot gases passed.

The course taken by the gases was from the furnace to the combustion chamber which might be common to several furnaces, through the nest of tubes to the smoke-box, and so to the funnel. This class of boiler was used for a long time in the French Navy. (Figs. 5 and 5A.)

Sometimes the box-shaped passage was retained, only filled

MARTIN OR COCHRANE BOILER.

Scale—1 cm. = 1 mètre = $\frac{1}{100}$.

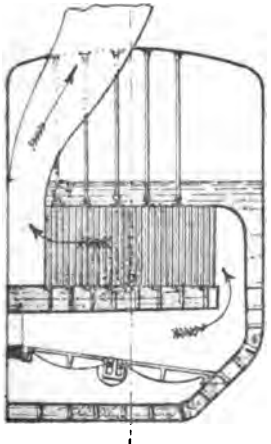

Fig. 6.

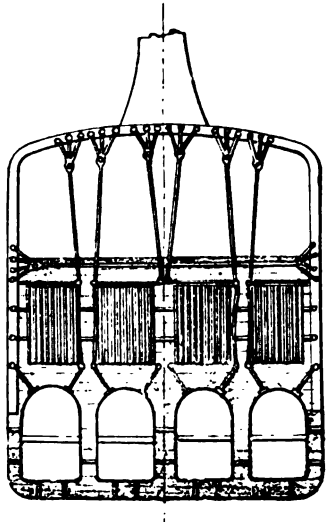

Fig. 6A.

up with a nest of vertical tubes, around which the flames passed on the outside, the water being on the inside.

This boiler, known as the Martin or Cochrane boiler (Figs. 6 and 6A), was adopted on several English passenger steamers, on the *Vanguard*, and in the American Navy.

13. *Cylindrical Boilers.*—The rectangular form of boiler,

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though well adapted to the form of the stokehold, had to be abandoned when higher pressures were adopted.

There were numerous attempts about this time to make boilers consisting of a simple nest of tubes and reservoirs attached, all heating being external; but these attempts had to be abandoned and boilers of large volume, similar to those at present in use, known under the name of marine boilers or Scotch boilers, as they were first used on the Clyde, came into use.

Cylindrical boilers, due to their form, stand the higher pressures better, and only need staying in one direction instead of three. The great drawback to the cylindrical form was the amount of water it contained, whereas with rectangular boilers largely composed of water-spaces, of which it was much easier to regulate the thickness, the total quantity of water contained could be considerably reduced. Cylindrical boilers are made with one, two, three, and four furnaces. Those having three or four furnaces have them at different heights from the stokehold floor; Figs. 7 and 7A show boilers with two furnaces; Figs. 8 and 8A, three furnaces. The same internal arrangements are met with as in the rectangular boiler, consisting of furnaces, combustion chambers, a nest of tubes and smoke-box, and the flat water-spaces met with round the combustion chamber are similar in both cases.

Cylindrical boilers are made single and double ended; the latter, shown in Figs. 9 and 9A, 10 and 10A, may have as many as eight furnaces. This arrangement is adopted to save weight and space.

Boilers of elliptical form were also tried, but were abandoned on the introduction of higher pressures.

The cylindrical type is that now almost universally adopted in the mercantile marine, but on account of the small amount of head room available on some men-of-war, in order to reduce the diameter, the tubes were placed as a continuation of the furnace, the combustion chamber being between the furnace and tubes. This type had a large amount of water in the neighbourhood of and surrounding the furnace, and so exaggerated the difficulty with regard to weight, which elliptical boilers had been designed to lessen.

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STANDARD CYLINDRICAL BOILER (1875).

Scale—2 cm. = 1 metre = $\frac{1}{50}$.

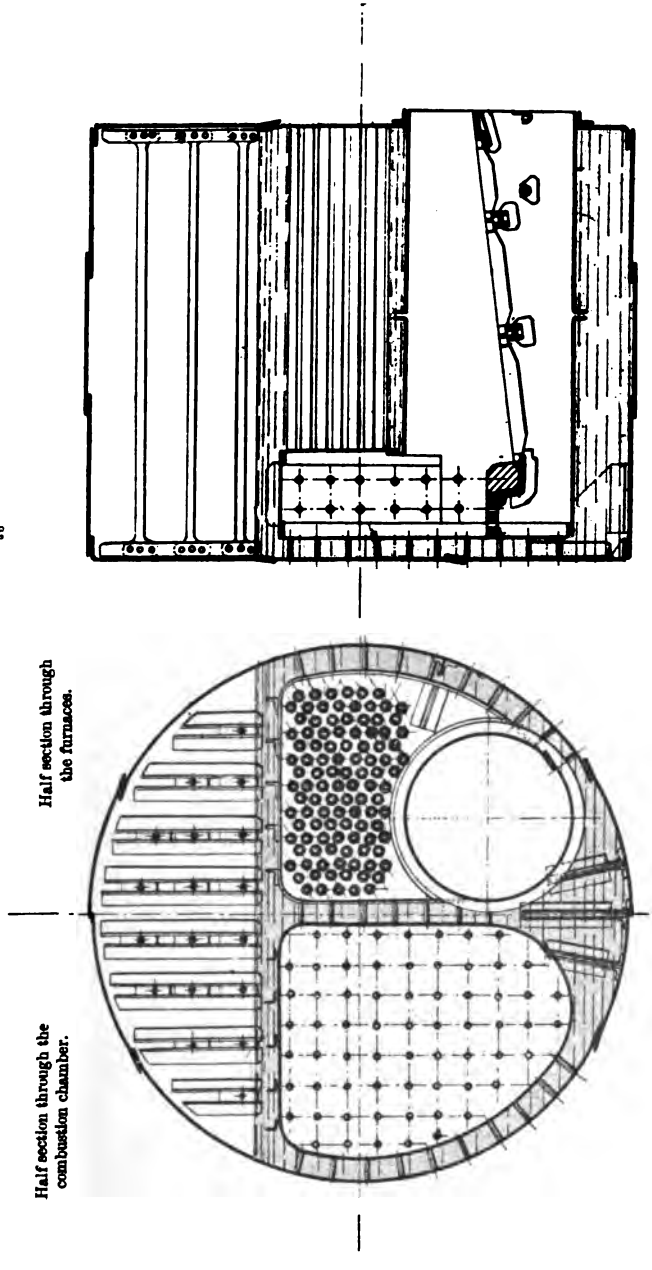

Fig. 7A.

Fig. 7.

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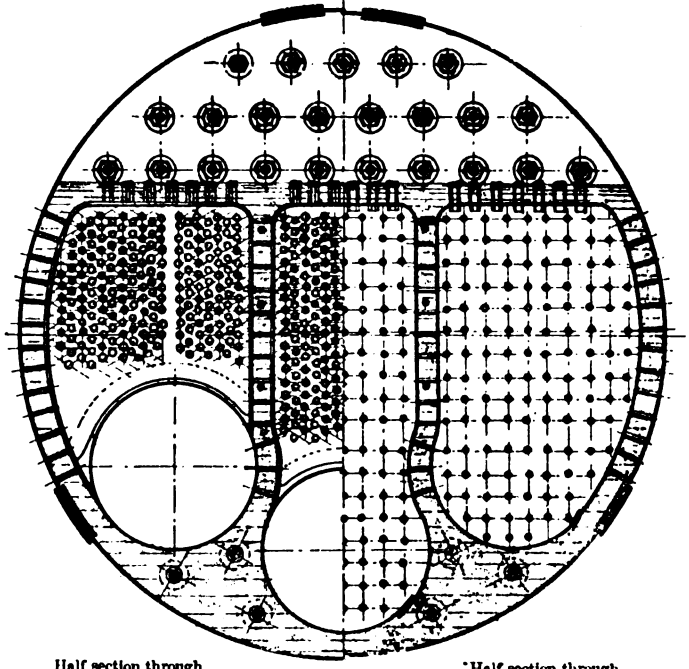
JEAN-BART

CYLINDRICAL RETURN-TUBE BOILER.

Scale—2 cm. = 1 mètre = $\frac{1}{50}$.



Half section through furnaces.

Half section through combustion chamber.

Fig. 8.

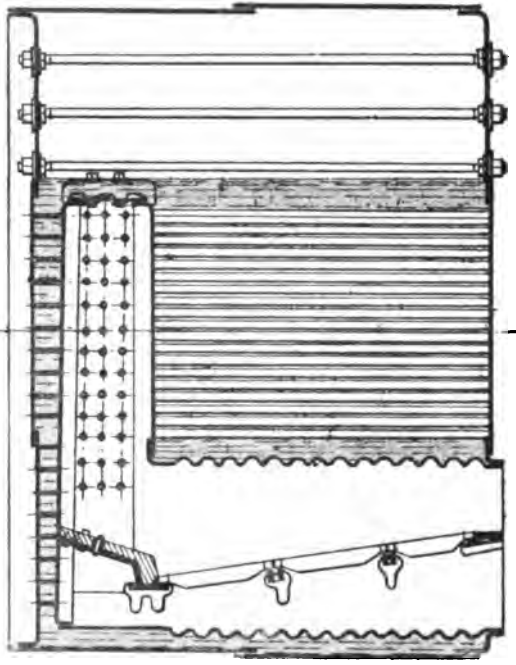


Fig. 8A.

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CÉCILLE

DOUBLE-ENDED BOILER.

Scale—15 mm. = 1 mètre.

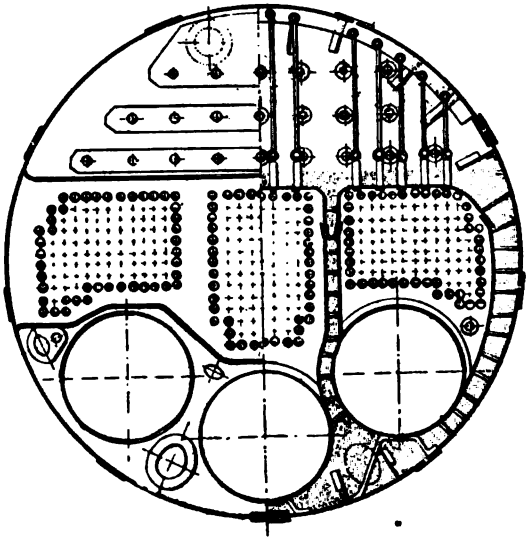

Fig. 9

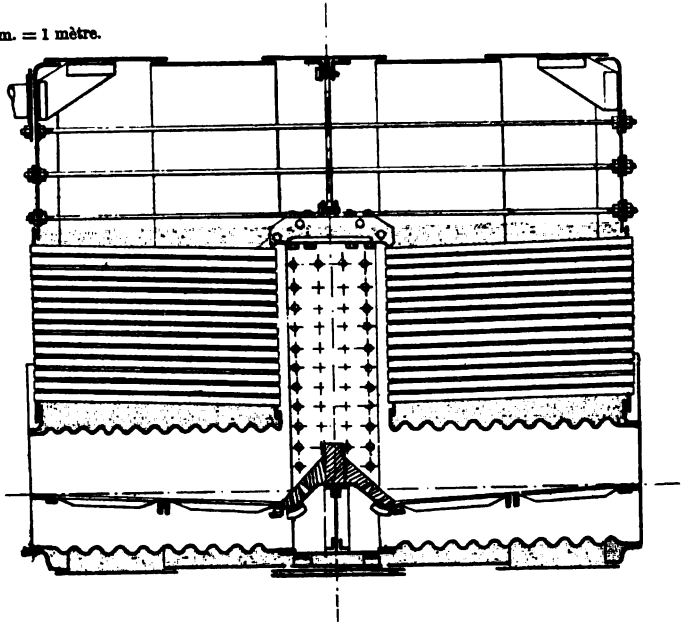

Fig. 9A.

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D'ENTRECASTEAUX

DOUBLE-ENDED BOILER.

Scale—15 mm. = 1 mètre.

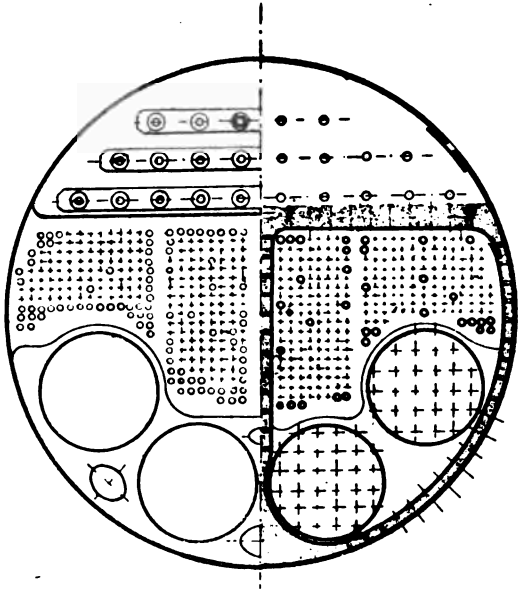

Fig. 10.

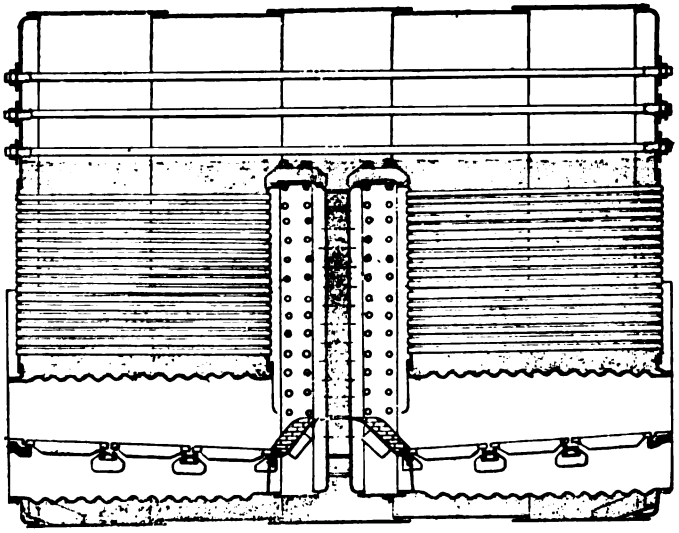

Fig. 10A.

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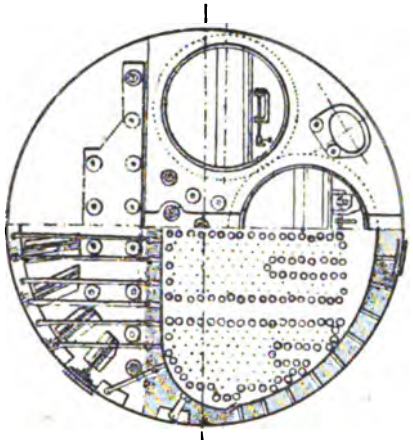

Fig. 11A.

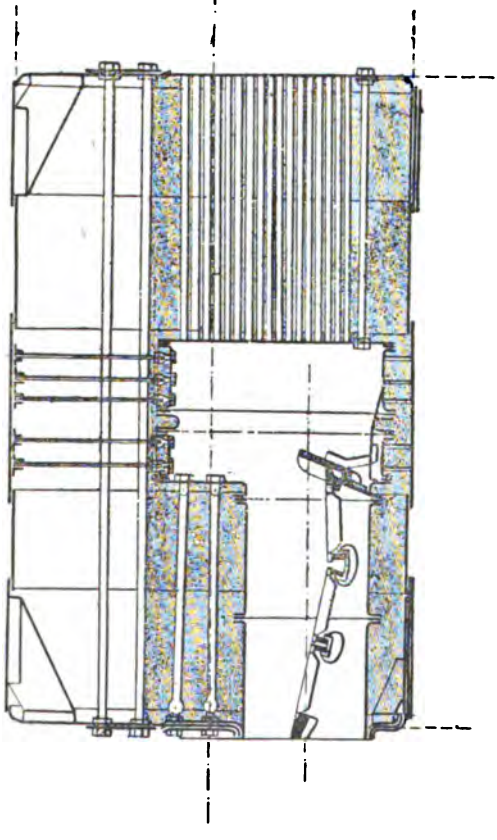

Fig. 11.

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14. *Locomotive Boilers.*—The necessity of reducing the amount of water led to the introduction of the locomotive type of boiler, in which the large rectangular furnace is surrounded by flat water-spaces, and the combustion chamber is entirely done away with. These boilers gave very good results on board the torpedo-boats when in the hands of thoroughly experienced persons, but they were not able to stand the long runs to which they would have been subjected on ordinary boats.

15. *Tubulous Boilers.*—The introduction of still higher pressures and the necessity of cutting down weights, especially in the navy, led to the introduction of boilers composed entirely

TORPEDO-BOAT BOILER—TYPE B.

Scale—15 mm. = 1 mètre.

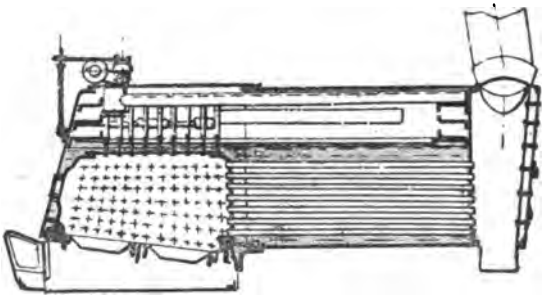

Fig. 12.

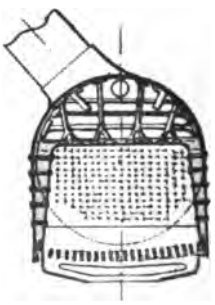

Fig. 12A.

of tubes filled with water and steam. Boilers composed of tubes, or tubulous boilers, are replacing the locomotive boilers on torpedo-boats, are beginning to be extensively used on despatch-boats, and have been used in the French and other navies on cruisers. The Messageries Maritimes have adopted the oldest and best known type of tubulous boiler on their passenger steamers.

The different types of tubulous boilers are so numerous that we cannot do more than give a general description of them, as we did of cylindrical boilers. In our more detailed examinations of them we shall divide them into three distinct groups.

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(*a*) *Boilers with Limited Circulation*, that is, serpentine or coil boilers, in which there is no circulation except that necessary to replace the water evaporated. The generating tubes, arranged more or less in the form of a coil and composed sometimes even

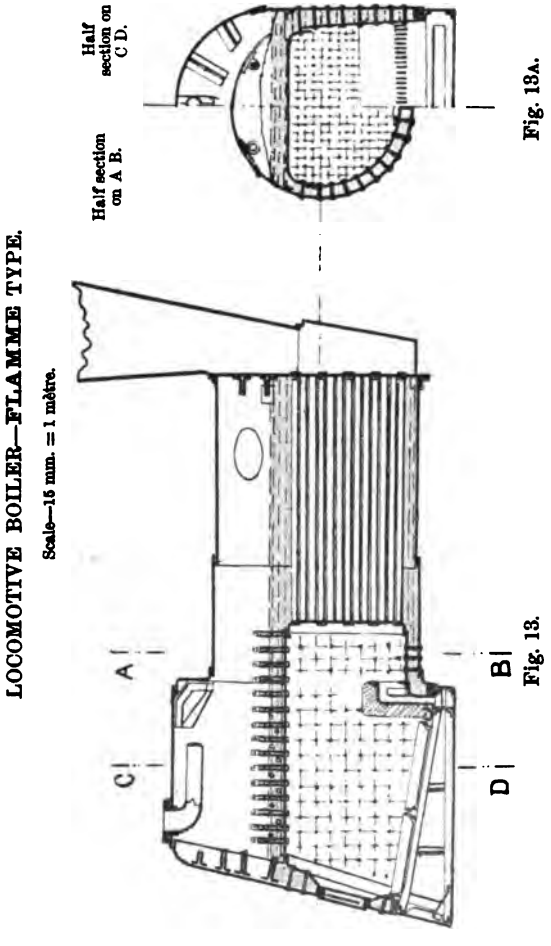

Fig. 13A.

Fig. 13.

of a single tube in a helical form surrounding the furnace, receive the feed-water at one end and discharge the steam at the other.

The Belleville boiler is the best known boiler of this type.

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BELLEVILLE BOILER.

Scale—15 mm. = 1 mètre.

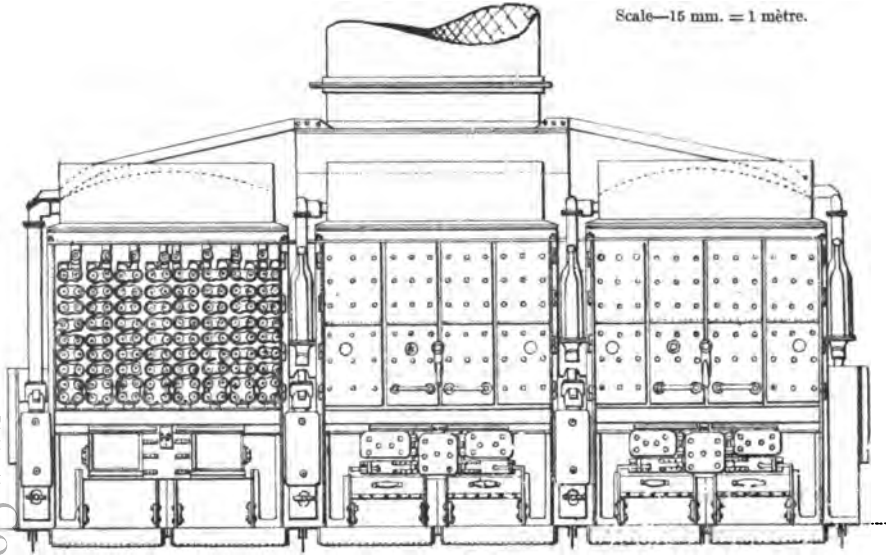

Fig. 41.

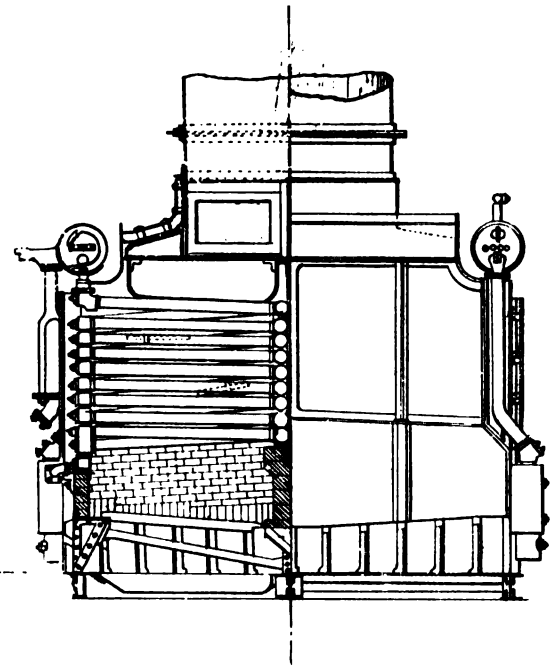

Fig. 41A.

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(*b*) *Boilers with Free Circulation.*—The chief characteristic of these is the presence of a vertical flat water-space at the front

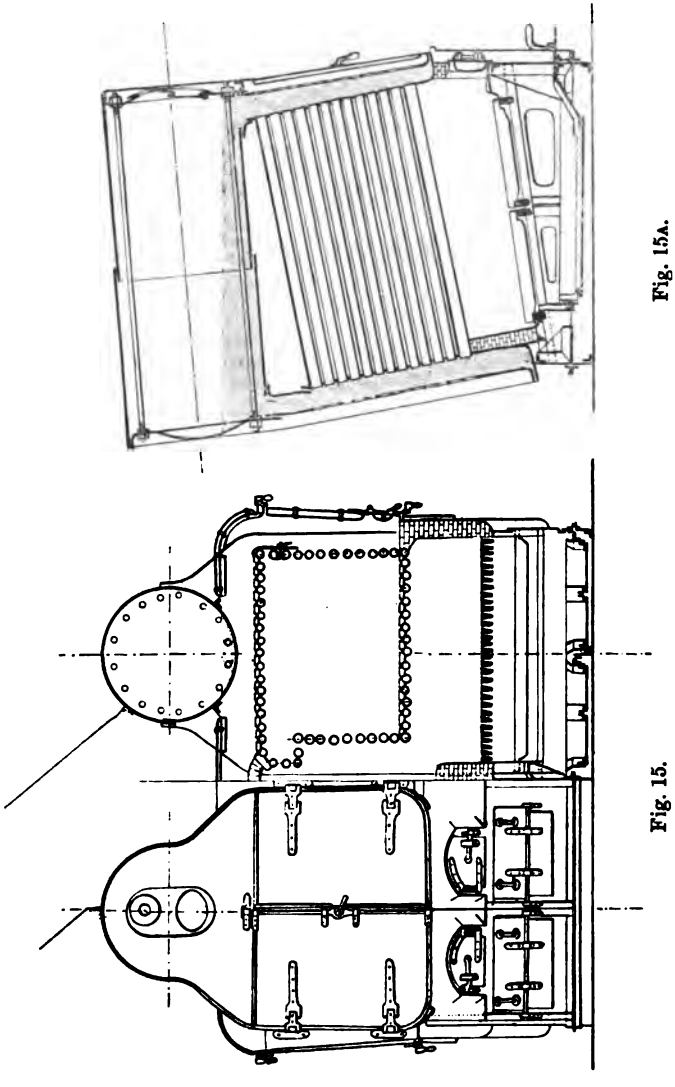

Fig. 15.

Fig. 15A.

and back of the boiler connected by horizontal or slightly inclined tubes.

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These tubes receive the water from one reservoir and discharge it into the other as steam. The current is, as a rule, much more active than in the previous case, and the steam gets away much more freely. The best-known boilers in France of this class are the Oriolle, D'Allest, and Niclausse.

(*c*) *Boilers with Accelerated Circulation, or Boilers with Horizontal Reservoirs placed at different heights.*—This class of boiler is characterised by the direction given to the water, which is as nearly vertical as possible in its passage between the reservoirs.

TORPEDO-BOATS, Nos. 172 to 176.

DU TEMPLE BOILER.

Scale—15 mm. = 1 mètre.

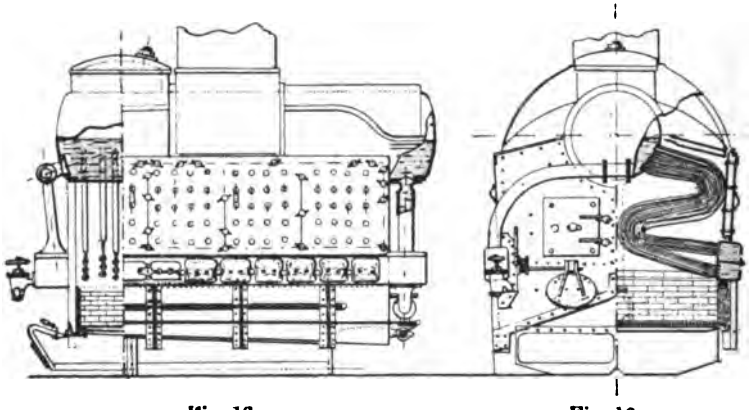

Fig. 16. Fig. 16A.

Large down-take tubes return the water from the top steam drum to the lower water drum.

Everything is thus arranged to facilitate a continued and general circulation.

The typical boiler of this class is the Du Temple boiler from which have sprung the Thornycroft, Normand, and other boilers. This classification into three distinct groups does not hold universally, as there are some intermediate types which it is very difficult to classify. They naturally fall into this classification from their general arrangement and mode of working.

The boilers of the first two classes are now being extensively

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used on shore, where they are entering into competition with the old cylindrical boiler, and have the advantages of greater immunity from danger of explosion; they are also fairly economical at the low rates of working at which they are run on shore.

The tubulous boilers of the third class are specially adapted to the requirements of the navy.

§ 2. NOTES ON THE GENERAL BEHAVIOUR OF BOILERS.

16. *Boiler Fittings.*—A boiler is really in principle a simple piece of apparatus, although it may be of delicate construction and need careful handling to obtain the best results. It consists of a chamber for the flames and a reservoir for the water placed next to one another, and it is difficult to discern beyond these any well defined or distinct organs. The flame chamber commences with the furnace, which consists of two parts, the furnace and the ash-pan, separated from one another by the grate. It is followed by a combustion chamber often difficult to distinguish from the flame passages, and it terminates in the smoke-box.

The water and steam reservoir, which is the boiler properly so called, always fulfils the same function whatever its form. It is sometimes fitted with a settling drum, where the solid matters contained in the water are deposited, and at the top a steam receiver, which enables the steam to be taken off well above the water-level.

The various parts of the boiler are stayed as occasion requires, and handholes are fitted for cleaning and inspection.

The boiler mountings are numerous and often complicated.

The funnel by creating a draught draws the air into the furnaces. It is a very simple, though not a very economical way, of procuring the necessary air for combustion.

To reduce the likelihood of accidents, there are nearly always two distinct systems of feed, one by the feed-pump in the engine-room and one by the donkey-pump in the stokehold.

Each system has its own piping, and must be capable of

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supplying all the water that may be required by the boiler. The feed-pumps are designed for ordinary use, and are under the control of the engineer in the engine-room; the donkey-pumps are only a standby in case of need, and are controlled by the stokers. The main feed-pumps are also occasionally placed in the stokehold. The feed system comprises all the fittings for purifying and heating the feed-water, questions which are daily growing in importance and receive more attention. Means for injecting lime into the feed-water are now usually fitted.

A very important fitting, especially on warships, is the fan which allows the draught to be varied at will independently of the funnel.

Several attempts have been made to use mechanical stokers, but so far without success. The only case where it has been successful is with liquid fuel.

To the above may be added those fittings more especially useful to increase the safety or security of the boiler; they are pressure-gauges, safety-valves, low-water alarms, water-gauges, and test-cocks. Float feed-regulators are also used to regulate the feed.

Lastly, there is the steam stop-valve and all the piping which may be considered an adjunct either to the boiler or the engines. Each boiler has its own stop-valve to enable it to be shut off at will from the rest of the boilers.

The steam piping, with all its subsidiary fittings, such as valves, expansion joints, traps, separators, is daily becoming more and more complicated. The complications introduced into the navy form a striking contrast when compared with the mercantile marine, even where the duties performed by the piping are more or less the same.

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CHAPTER III.

BRIEF DESCRIPTION OF MARINE ENGINES.

§ 1. GENERAL CONSIDERATIONS.

17. *Working Conditions of Marine Engines.*—The marine engine and boiler being so closely connected together, and forming as a whole the propelling machinery of a vessel, some brief elementary remarks on marine engines will not be out of place.

The conditions under which a marine engine is called upon to work are different in many respects from those obtaining in land engines; for instance, the question of weight and consumption of steam are of very much greater importance in the first case.

The speeds of marine engines are, as a rule, higher, since, by increasing the revolutions of the engines, their power may be augmented without at the same time proportionally increasing their weight. This bears a close analogy to the use of forced draught for increasing the power of a boiler.

By increasing the boiler pressure and expanding the steam successively in two, three, or more cylinders, economy in steam consumption has been realised.

Marine engines are always condensing engines, which, from an economical point of view, is in their favour. It is frequently impossible, for want of circulating water, to secure this advantage for land engines.

The facilities for manœuvring the engines, stopping, starting, reversing, etc., have to be much greater on marine engines, as the exigencies of navigation and war render this imperative.

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The screw having now almost entirely replaced the paddle in the mercantile marine, except in the case of a few river or cross-channel steamers, and having completely done so in the navy, the screw engine only need be dealt with.

§ 2. CLASSIFICATION OF ENGINES.

18. *Vertical Engines.*—Vertical engines, with their cylinders directly over their shafting, are universally used in the mercantile marine, where there is never any want of head-room, and the greater facility they afford for inspection while running has led to their general adoption in the navy.

To economise floor space, tandem-engines, with their cylinders one on top of the other, are sometimes adopted in the mercantile marine.

On warships, the necessity of protecting the engines, either by keeping them under the armoured deck, or under the water-line, led to the introduction of the horizontal type. The horizontal engine has, however, been gradually abandoned in favour of the vertical engine.

19. *Horizontal Engines.*—Various kinds of horizontal engines were adopted, such as the trunk engine, return connecting rod, etc., all of which are too well known to need detailed description here.

20. *Nomenclature Employed.*—The cylinder receiving the high-pressure steam from the boiler is always known as the high-pressure cylinder, that exhausting into the condenser as the low-pressure cylinder. In a triple-expansion engine, the cylinder between the high and low-pressure is known as the intermediate cylinder, and in the case of a quadruple-expansion engine, the two cylinders between the high-pressure and low-pressure are known as No. 2 and No. 3 cylinder; the end of the cylinder nearest the crank is known as the bottom of the cylinder, and the opposite end as the top of the cylinder.

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§ 3. THE PRINCIPAL PARTS OF THE ENGINE.

21. *Course of Steam through the Engines.*—The steam enters the engines through the main stop-valve and throttle-valve.

This latter valve, which is of great service to the engineer in manœuvring his engines, can also be used as a primitive kind of reducing valve.

The steam then passes direct into the high-pressure valve casing, which may or may not be fitted with an expansion-valve. The starting engine, fitted on large marine engines for reversing purposes, is also used to vary the expansion of the steam in the cylinders. Slots are generally provided on the levers fitted to the way-shaft to enable the expansions in the different cylinders to be altered independently within certain limits.

After passing through the cylinders, the steam is exhausted into a surface condenser, which is a necessity, on account of having to feed the boilers with fresh water; and this is a matter of the very greatest importance, as we shall see further on when dealing with tubulous boilers. The various pumps, such as circulating-pump, feed-pump, air-pump, etc., need not be dealt with here.

22. *Moving Parts of Engine.*—A few of the various moving parts of the engine may be enumerated, though they cannot be described in detail. The piston-rod is fitted into the piston and passes through the stuffing-box, being fitted at the end with a crosshead and guide slipper. The connecting-rod is attached at its upper end to the crosshead, and its lower to the crank-pin. The shafting consists of crank-shaft, thrust-shaft, intermediate lengths, and tail, or, propeller shaft. This latter passes through the stern-tube, and carries on its outer end the propeller boss, to which the screw blades are attached. The thrust-block takes up the thrust of the propeller and transmits it to the hull of the vessel. The slide- and piston-

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valves distributing the steam to the various cylinders are driven by eccentrics off the crank-shaft. Various kinds of valve-gear, both of single and double eccentric types, have been adopted, but the simplest and most largely used is the ordinary Stephenson double-link motion.

A small auxiliary engine is usually fitted for turning the engine in port when under repairs.

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CHAPTER IV.

PRODUCTION OF HEAT FROM COAL.

§ 1. GENERAL CONSIDERATIONS.

23. *Boiler Efficiency.—Total Heat Tables.*—The quantity of water evaporated in a boiler is always a matter of the greatest importance, and determines the efficiency of any given type; the efficiency being the ratio between the quantity of heat utilised in evaporation and that which would have been produced had the combustion been perfect.

The properties of coal will be dealt with later. A Table is subjoined giving the amount of heat necessary to raise 1 lb. of water from 32° Fahr. to $t°$ Fahr., and to transform it into dry steam at that temperature. (See Table on next page.)

The second factor determining the total evaporation of a boiler is the total quantity of coal that can be burnt. This depends mainly upon the area of grate and the air pressure.

24. *Various Considerations affecting the Efficiency of Boilers.*—Over and above the efficiency, the value of any particular type of boiler must be arrived at by taking into consideration the life of the boiler and its liability to accidents and breakdowns. The efficiency and safeness of any boiler depend upon its design, and the care exercised in its construction, and to a certain extent upon the care with which it is handled, and the proficiency of the stokers.

We shall, however, direct our attention more particularly to the construction of boilers, as it is difficult to lay down hard and fast rules for their management, except in regard to the old tubular boiler, where long experience renders this possible.

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Total pressure in Pounds per Square Inch.	Temperature or boiling point in Degrees Fahrenheit t.	Δt.	Total heat required to generate 1 lb. of Steam from Water at 32° F. under constant pressure Q.	Δ Q.
1	102·0	..	1113·05	..
2	126·4	24·4	1120·49	7·44
3	141·6	15·2	1125·14	5·65
4	153·1	11·5	1128·63	3·49
5	162·3	9·2	1131·44	2·81
6	170·1	7·8	1133·82	2·38
7	176·9	6·8	1135·90	2·08
8	183·0	6·1	1137·75	1·85
9	188·4	5·4	1139·40	1·65
10	193·3	4·9	1140·89	1·49
11	197·8	4·5	1142·26	1·37
12	202·0	4·2	1143·55	1·29
13	205·9	3·9	1144·72	1·17
14	209·6	3·7	1145·87	1·15
14·7	212·0	2·4	1146·60	0·73
15	213·1	1·1	1146·93	0·33
20	228·0	14·9	1151·47	4·54
25	240·5	12·5	1155·29	3·82
30	250·5	10·0	1158·34	3·05
35	259·0	9·5	1160·95	2·61
40	267·0	8·0	1163·38	2·43
45	274·3	7·3	1165·60	2·22
50	281·0	6·7	1167·64	2·04
55	287·0	6·0	1169·49	1·85
60	292·6	5·6	1171·18	1·69
65	297·8	5·2	1172·76	1·58
70	302·8	5·0	1174·29	1·53
75	307·5	4·7	1175·74	1·45
80	312·1	4·6	1177·13	1·39
85	316·3	4·2	1178·41	1·28
90	320·3	4·0	1179·63	1·22
95	324·0	3·7	1180·77	1·14
100	327·7	3·7	1181·88	1·11
110	334·6	6·9	1183·99	2·11
120	341·1	6·5	1186·00	2·01
130	347·2	6·1	1187·85	1·85
140	352·9	5·7	1189·57	1·72
150	358·3	5·4	1191·22	1·65
160	363·4	5·1	1192·77	1·55
170	368·3	4·9	1194·27	1·50
180	373·0	4·7	1195·70	1·43
190	377·5	4·5	1197·07	1·37
200	381·8	4·3	1198·39	1·32
225	391·6	9·8	1201·39	3·00
250	400·8	9·2	1204·18	2·79
275	409·1	8·3	1206·72	2·54
300	417·1	8·0	1209·16	2·44

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These rules apply more or less to tubulous boilers, with the addition of some special precautions for the maintenance of the fires, supervision of the water-level, and management of the feed.

§ 2. FUEL AND GRATES.

25. *The Composition of Coal and its Analysis.*—Coal employed for firing boilers is composed mainly of two elements, carbon and hydrogen, associated with oxygen, nitrogen, sulphur, and certain mineral matters which constitute the ash. The sulphur is sometimes met with in appreciable quantities, generally in the form of pyrites.

One pound of hydrogen, when burnt, develops 62,030 British thermal units, or B.T.U., and requires for combustion 8 lbs. of oxygen.

Pure carbon (the result of the calcination of wood) when completely burnt and transformed into carbonic acid develops 14,540 B.T.U. per pound, and in doing so consumes 5·89 pounds of oxygen. The calorific value of carbon diminishes slightly if very compact; it falls in the case of the diamond to 13,860 B.T.U.

Charcoal, when transformed into carbon monoxide by its combination with 1·33 pounds of oxygen, develops 4,450 B.T.U.

Carbon monoxide develops per pound of carbon 10,090 B.T.U., thus making up the 14,540 B.T.U. The difference of 5,640 B.T.U. between 10,090 and 4,450 is the latent heat of the carbon vapour.

The calorific value of coal is determined by means of a calorimeter. The latest form of this instrument is the "bomb" calorimeter, devised by MM. Berthelot and Vieille, in which combustion takes place under pressure in pure oxygen. This is a very simple instrument, and can easily be used by engineers interested in the study of coal.

The analysis of coals, and the determination of their calorific value, has been undertaken by a large number of experimenters. The results obtained are mainly for English coals. Full information on these points will be found in the works of Messrs. Stromeyer and Seaton.

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—	Calorific value.	Results of Elementary Analysis.						
		C	H	O	S	N	Water.	Ash.
	B.T.U.							
Nixon Navigation, Glam.	15,010	88·03	4·11	1·98	0·66	0·96	1·02	3·22
Tyldesley, Theperley & Co.	11,610	68·18	4·78	4·86	1·39	1·22	4·72	14·90
Tyldesley Coal Co.	12,730	74·46	5·10	8·25	0·49	1·53	6·07	4·09
Bickshaw Main	13,430	78·93	4·90	7·24	1·04	1·56	4·36	1·96
Pemberton	13,040	72·41	5·16	8·84	0·93	1·41	6·70	4·55
Cramhawke	13,420	69·77	4·82	12·44	1·17	1·33	7·15	3·31
Wigan	13,590	76·49	4·96	8·46	1·07	1·44	4·84	2·75
Welsh Ebbw Vale	16,221	87·78	5·15	0·39	1·02		3·66	
Welsh average	14,858	83·87	4·79	4·15	1·43		5·89	
Newcastle average	14,820	82·12	5·31	5·69	1·24		5·12	
Lancashire average	13,918	77·90	5·32	9·53	1·44		6·18	
Patent Fuel: Warlichs	16,495	90·02	5·56	..	1·62		..	
Coke: best Durham	12,832	85 to 92	..	..	0·25 to 2		4 to 12	
Petroleum	11,244	84·7	13·1	2·2	0·00		0·00	

To these may be added the following figures of three French coals given by M. Scheurer-Kestner:—

—	Calorific value.	C	H	O + S + N.
	B.T.U.			
Ronchamp	16,440	89·09	5·09	5·82
Anzin	16,660	84·45	4·21	11·32
Anthracite	17,020	88·03	4·11	3·6

A number of attempts have been made to express algebraically the calorific value in terms of the results given by the elementary analysis, but they have so far not been successful. The oldest formula, that of Dulong, is simply—

$$14540\ C + 62030\left(H - \frac{O}{8}\right),$$

and neglects, amongst other things, the heat of dissociation.

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26. *Gruner's Classification.—Qualities of Coal Specified for the French Navy.*—M. Gruner, in his treatise on Metallurgy, has given a classification of coals by using the length of the flame as the classifying agent; this classification follows the order of their densities, and most probably in the order of their geological formation from the lignite up to the anthracite coals. The following Table gives a *résumé* of their classification:—

		Residue of Coke.	Volatile Matter.	Specific Gravity.	Calorific Value.
		Per cent.	Per cent.		B.T.U.
	Lignite	30 to 45	70 to 55	1·15 to 1·20	12,600 to 14,400
Coals.	1. Long flame	50 „ 60	50 „ 40	1·25	14,760 „ 15,000
	2. Bituminous—long flame	60 „ 68	40 „ 32	1·28 „ 1·30	15,300 „ 15,840
	3. Bituminous—ordinary flame	68 „ 74	32 „ 26	1·30	15,840 „ 16,740
	4. Bituminous—short flame	74 „ 82	26 „ 18	1·30 „ 1·35	16,740 „ 17,280
	5. Hard — little removed from anthracite	82 „ 90	18 „ 10	1·35 „ 1·40	17,100 „ 16,560
	Anthracite	90 „ 95	10 „ 5	1·40 & above	16,560 „ 16,200

Gruner's method of analysis consists in the slow distillation of the coal until completely calcined. The products of distillation consist of ammoniacal liquid, tar, and gases containing carbon in varying proportions.

The analysis of coal No. 1 and coal No. 5 gives a nearly constant value for hydrogen, varying irregularly between 5 and 4 per cent. The quantity of carbon only varies between 75 and 93 per cent. instead of between 50 and 90 per cent., and the quantity of oxygen and nitrogen combined drops from 20 to 3 per cent.

Coals Nos. 1 and 4, for various reasons, have the common characteristic of not caking when being converted into coke.

Coal No. 4 is specially adapted for burning in marine boilers. It is to this class that the English Cardiff coal and the French Anzin coal belong.

Coals containing 14 per cent. of volatile matter may be used

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for briquettes. This corresponds very closely to the Anzin coal largely used in the French Navy.

The 8 per cent. of pitch added as a cementing agent increases the proportion of the volatile substance by 4 per cent. The briquettes made of poor coals, with only 10 per cent of volatile substances, break up very easily in the furnace and fall through the bars. When new supplies of coal have to be furnished for the French Navy, the minimum proportion of 73 per cent. of coke is insisted upon prior to their being submitted to their reception tests. The calorimetric values and the elementary analysis give approximately the value of the coal as a combustible for marine purposes. The analysis and classification given in Gruner's Table give very reliable results, but in order to be perfectly sure of its value the coal should be tried on board, under ordinary service conditions.

27. *Coal Reception Tests in Force in the French Navy.*—The instructions for testing, which are still in force, dating from the 25th January, 1861, and 8th April, 1864, were issued under M. Dupuy de Lôme. They are drawn up with the object of arriving at the best coal for the rectangular return-tube boilers which were exclusively used at that time.

The evaporative power of the coal is determined by measuring very exactly the quantity of water evaporated per pound when burning half a ton of coal in a standard boiler.

Note is taken of the rate of combustion, and a distinction is drawn between the quick-burning and slow-burning coals. This is determined by the quantity of coal burnt per square foot of grate per hour at natural draught. The desire to burn a large quantity of coal at natural draught led to the use of quick-burning coals occupying a position above No. 4 of Gruner's scale. This has lost its importance since the introduction of forced draught which permits of the use of even anthracite coals.

The third class of measurements taken refer to the quantity of ashes and clinker remaining after combustion, and the amount of soot deposited in the tubes. These measurements are important, as cleaning the fires and sweeping the tubes are

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in themselves a laborious operation and may strain the boiler, not to mention the loss of heat that they give rise to.

The amount of ash left after calcination is measured in a crucible; this test also gives the proportion of coke to the volatile constituents.

Lastly, the cohesion of the coal is measured in order to test its ability to stand manipulation on board without crumbling to dust. No alterations have been introduced into these tests for cohesion since their first introduction. The coal is placed in a cylindrical receptacle which is given fifty turns in two minutes. It is then passed through a sieve, and the ratio of the coal remaining in the sieve to the total quantity under test is taken as the measure of its cohesion.

The early trials with the standard boiler gave somewhat unexpected results, the most important of which are given in M. Picart's report, published in the *Mémorial du Génie Maritime* in 1867. This report showed that the mixture of Cardiff and Newcastle coal used on all the trials was inferior to the Anzin coal in regard to evaporative efficiency, quickness of burning, and cohesion. The supply of Cardiff coal was stopped, and the manufacture of briquettes from the North of France coal-beds was commenced and further developed.

For twenty years the tests have been carried out in the different dockyards on the old rectangular boiler with a pressure of 25 lbs. to the square inch, which is sufficient for all comparative tests, and a large amount of information has been collected on the various French coals. When pushing the fires to determine the quickness of burning of the coals 20·5 to 26·6 lbs. per square foot have been burnt. The water evaporated, which was as low as 6 lbs. per pound of coal for inferior coals, with good briquettes rose to 8·6 lbs.

The quantities of clinker, ashes, and soot varied largely, but a good result, though rarely attained, and one easily to be remembered, is 3 per cent. clinker, 3 per cent. ash, and 0·3 per cent. soot.

As the old rectangular boilers required renewing they were replaced by cylindrical boilers with a pressure of 114 lbs. per square inch.

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This change has more value in arriving at a comparison between the two types of boilers than in comparing the various classes of coal.

The quantity of water evaporated by the new boilers, due to the better arrangement of tubes and furnace, is naturally slightly higher, and further, the total heat of steam at 114 lbs. per square inch is only $\frac{1}{40}$ greater than that at 28 lbs. per square inch. Good briquettes now give an evaporation of 9·6 lbs. Besides the old trials, where the fires were slightly pushed, slow combustion trials were also carried out, but the results were so nearly identical as not to warrant the extra expense entailed.

Forced draught trials have now been added, in which 30 lbs. were burnt per square foot of grate, and the evaporation dropped about $\frac{1}{7}$, seldom exceeding 8 lbs. per pound of coal.

The accompanying Table gives the tests specified, which are usually exceeded. The evaporation given corresponds to a combustion of 20 lbs. per square foot per hour:—

Name of Fuel.		Water evaporated per lb. of Coal.	Cohesion.	Ash remaining in the Calorimeter.
		Lbs.		Per cent.
Anzin briquettes	for torpedo-boats	8·6	0·58	3·25
	ordinary . . .	8·4	0·55	7
Bessèges briquettes	for torpedo-boats	8·6	0·53	3·25
	ordinary . . .	8·5	0·53	5

It is by repeated tests, carried out on the standard test boiler, that briquettes equal to the well-known Nixon's navigation coal have been obtained.

28. *Tests in Different Countries.—Reduction to "from and at 212°."*—Evaporation trials are now carried out with great exactness in most of the leading countries. They include tests for the dryness of the steam produced, analysis of funnel gases, and other usual data.

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In order to arrive at any exact comparison, account must be taken of the temperature from which the water was evaporated; in France this is usually reduced by means of a simple calculation to 10° C. (50° Fahr.) The pressure and temperature of the steam must also be taken into account. This second correction, which amounts to 36 thermal units when the pressure rises from 30 to 170 lbs. per square inch, only amounts to 16 thermal units when the pressure rises from 170 to 310 lbs. per square inch. The latter correction, therefore, is not of much importance when comparing boilers of very high pressure.

In England the correction to "from and at 212° Fahr." is always used to obviate the variations of temperature in the water and the steam. A pound of water evaporated from and at 212° Fahr. necessitates an expenditure of 966 B.T.U.

Taking a boiler which evaporates 9 lbs. of water from 50° Fahr. at a pressure of 284·4 lbs. per square inch, the correction will be as follows: To 284·4 lbs. must be added the atmospheric pressure, 14·7 lbs.; this gives the absolute pressure as 299·1 lbs. per square inch, and the corresponding temperature is 416·8° Fahr. Then the equivalent evaporation "from and at" is given by the expression—

$$9 \times \frac{1114 - 0{\cdot}7 \times 416{\cdot}8 + (416{\cdot}8 - 50)}{966} = 11{\cdot}07 \text{ lbs.},$$

a result very different from the original 9 lbs. of water. The quantity—

$$\frac{1114 - 0{\cdot}7 \times 416{\cdot}8 + (416{\cdot}8 - 50)}{966}$$

is called the *factor of evaporation.*

Measuring the efficiency by means of the water evaporated is always inexact, as no account is taken of the dryness fraction of the steam. For this reason the consumption of coal per horse-power is the best basis of comparison.

29. *Description of Different Types of Grates.*—Coal is burnt on various descriptions of grates, which are nearly always

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composed of steel or wrought iron, or sometimes, with certain kinds of coal, of cast iron.

The type used in the French Navy (Fig. 22) has a maximum length of 2 ft. 9½ in., a thickness on top of 1 in., with ⅝ in. air spaces.

The spacing of the bars is kept constant by means of distance pieces, a small amount of play being allowed for expansion.

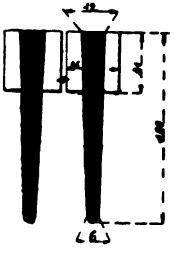

Fig. 22.

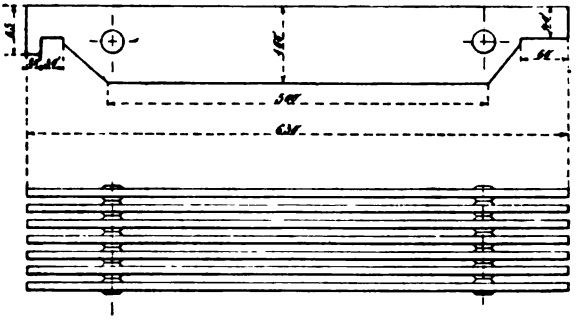

Fig. 23.

Fig. 24.

Fig. 23A.

This form of grate is well adapted for burning Anzin coal with natural draught when the fire is about 6 ins. thick.

The English Admiralty uses much thinner bars, only about ⅜ in. thick, spaced ¼ to $\frac{5}{16}$ in. apart, as shown in Figs. 23 and 23A.

In England the bars are sometimes riveted up together, two or three at a time, with distance pieces between them. This arrangement, which is also in use on several of the French torpedo-boats, makes the bars more rigid, and enables them to be made of greater length, up to, say 4 ft. 3 in. or 4 ft. 6 in.

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In America the upper surface of the bar is sometimes recessed (Fig. 24), and adds to the length of life of the bar.

Care is always taken to leave very little play between the side of the furnace and the bars, in order to avoid an influx of air and a consequent high temperature at this point.

For a long time a system of grate was employed on the Belleville boiler consisting of thin bars pressed into a special form and riveted up in pairs. This arrangement is shown in Fig. 25. The air enters through the hexagonal holes shown in Fig. 25A.

MM. Niclausse use bars very close together, the air

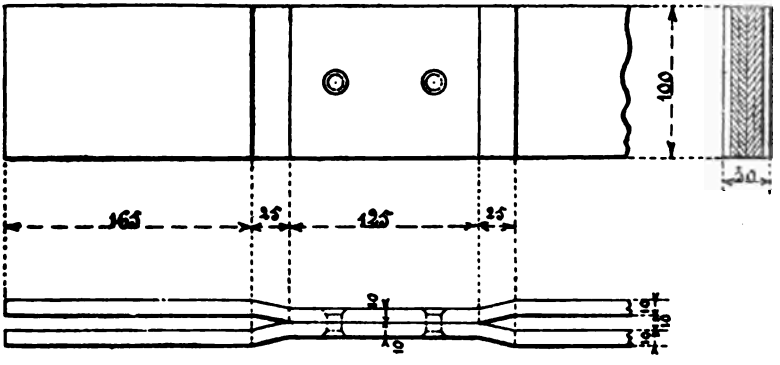

Fig. 25.

passages being only $\frac{1}{16}$ to $\frac{1}{8}$ inch, the breadth of the bar being about $\frac{3}{8}$ in.

The ends of the fire-bars rest on bearers formed of two cross-bars riveted together with a space between them. At the fire-door end they rest on a broad cast-iron plate of sufficient breadth to prevent combustion taking place near the fire door. The bearers and sole-plate are held in position by pieces of angle-bar riveted to the sides of the furnace.

In America various kinds of grates with movable bars have been used to facilitate stoking, having been adopted by the American Navy from locomotive practice.

The grate terminates at the back end in a bridge resting on a cast-iron or cast-steel cross-piece. The bridge keeps the coal

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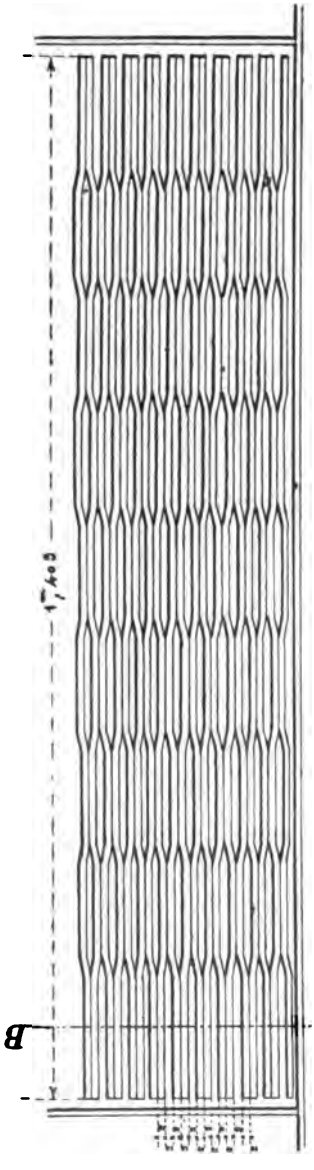

Fig. 25A.

Fig. 25B.

from falling off, causes the flame to rise, and closes the end of the ashpit, and it is often provided with holes for the passage of air.

§ 3. NATURAL DRAUGHT.

30. *Calculations for Determining the Draught. — The Velocity of Air corresponding thereto.*—The draught is due to the difference in weight between the hot column of air in the funnel calculated above the grate and the cooler column of air outside the boiler.

The depression existing in the boiler resultant from the difference above alluded to, and the velocity consequent upon the same, is usually measured, not in the furnace, but in the smoke-box. The instrument used in measuring this depression generally consists of a bent glass tube containing water, having one of its ends or legs in direct communication with the interior of the smoke-box where the depression exists, the other end being open to the atmosphere.

The draught thus measured is expressed in so many inches of water.

The column of air at a

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temperature of 572° has a specific weight of about half that of the external air.

If H be the height of the funnel above the bars, and the velocity be taken as uniform, the depression at the base of the funnel would be ½ H. Expressing this in inches of water we have—

$$(1) \qquad h = \tfrac{1}{2} \text{H} \times \frac{0{\cdot}0000466}{0{\cdot}03611} \times 12 = 0{\cdot}008 \text{ H}.$$

Where H equals the height of the funnel in feet, and h the height of the water column in inches. The weight of 1 cubic in.

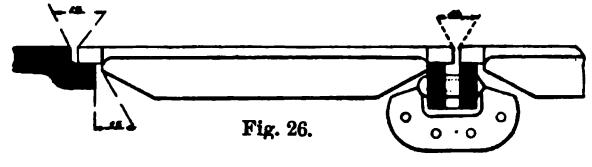

Fig. 26.

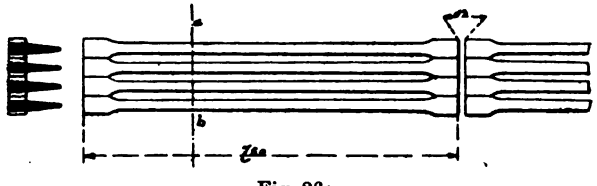

Fig. 26A.

of air at 32° Fahr. is 0·0000466 lb., and that of 1 cubic in. of water 0·03611 lb.

Thus, at the base of a funnel 66 ft., 49 ft., or 33 ft. high the depression will amount to 0·53 in., 0·39 in., 0·26 in. of water respectively, on the supposition that the mean temperature of the gases in the funnel is 572° Fahr., and that the movement of the column of air is not obstructed.

Let us consider now the varying speeds of the different portions of the column of air on the assumption that it is unobstructed. Let V_1 and V_2 be the speed in feet of the column of gases at two different points, at sensibly the same height, between which there is no resistance to motion, h_1 and h_2 the depression at these points expressed in inches

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of water, δ_1 and δ_2 their respective specific weights in relation to air.

The following relations will hold between V_1, V_2 and h_1, h_2 :—

$$(2) \qquad \delta_2 \frac{V_2^2}{2g} - \delta_1 \frac{V_1^2}{2g} = 108\,(h_2 - h_1);$$

or, using Δ to denote a small difference—

$$\Delta \frac{\delta V^2}{2g} = 108\,\Delta h;$$

replacing g by 32, we get approximately—

$$\Delta\,\delta\,V^2 = 6900\,\Delta\,h.$$

For hot air when $\delta = \frac{1}{2}$—

$$\Delta\,V^2 = 13800\,\Delta\,h;$$

for cold air when $\delta = 1$—

$$\Delta\,V^2 = 6900\,\Delta\,h.$$

If, for example, we consider the entrance of the cold air into the furnace without resistance, for a depression of 0·4 in. in the furnace, V = 52·5 ft. per second, and for a depression of 0·5 in., V = 58·7 ft. per second; these figures will only hold for the admission of air above the grate without resistance, and in such quantities that the value of h is not diminished. When the furnace doors are thrown full open the influx of air increases the resistance through the tubes, smoke-box, funnel, etc., and at the same time reduces the temperature. This largely diminishes the depression above the grate, and consequently the air does not enter the furnace at the speed above given by formula 4.

31. *Actual Speed of Gases.—Resistance due to the various parts of a Boiler.—Section of Passages required.*—Formula 4 does not even hold approximately, if we consider the air as entering from the ashpit doors.

It has been observed that the velocity of the air is 12·73 ft. on entering the ashpans for a depression of 0·52 in.

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in the ashpans, which corresponds to a depression of 0·43 in. in the furnace. If the air spaces between the furnace bars are equal to 60 per cent. of the grate surface, or say three times the section of the ashpit doors, the speed of the air through the bars will only be about 4·26 ft.

Calculating the depression for a speed of 12·73 ft., we have—

$$\Delta h = \frac{12{\cdot}73^2}{6900} = 0{\cdot}023 \text{ in.},$$

a very small fraction of the whole draught.

At the base of the funnel the velocity of the gases is much greater than through the ashpans, on account of the reduced section, and also that the volume of the gases is increased, due to the increased temperature.

To the weight of the column of air must be added also the weight of the products of combustion.

Supposing the section of the funnel to be three-quarters of the section through the ashpits, the volume of the gas will be doubled when raised to 572°, and therefore the speed will be 2·66 times that through the ashpits. The increase of weight, amounting to about $\frac{1}{20}$, may be neglected. The value of Δh, therefore, at the base of the funnel may be taken to correspond to about—

$$0{\cdot}023 \times 2{\cdot}66^2 = 0{\cdot}16.$$

The energy absorbed in putting the column of gases in motion is small compared with that absorbed in overcoming the resistance of obstructions, of which thus far we have taken no account.

Neglecting the resistance due to the ashpits, which is not great, the draught of 0·51 in. may be divided up as follows in a return tube-boiler:—

	Inch.
Resistance due to the funnel, uptakes and smoke-box .	0·02
„ „ tubes	0·11
„ „ fire-box, bridge, furnace . .	0·06
„ „ fire of moderate thickness . .	0·31
„ „ inertia of column of gases . .	0·02
Total.	0·51

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In the above division the total draught of 0·51 in. is measured from the fire-bars, thus neglecting the height of the smoke-box, where the draught is usually measured. The actual readings on the gauge would be 0·02 in. in the ashpit, 0·33 in. in the furnace, 0·39 in. in the combustion-chamber at the back tube-plate, and 0·51 in. in the smoke-box.

As a matter of fact the movement of the gases is by no means uniform, and is subjected to great fluctuations. The following Table is of interest when considering the movement of the gases as a whole:—

—	Section.	Temperature.	Approximate Velocity.
		Degrees Fahr.	Feet per second.
Ashpan doors	0·2	86	13·12
Air-passages through grate	0·33	..	..
„ „ the coal.	0·21 (assumed)	2912	91·86
Area above bridge	0·21	2192	75·46
Combustion-chamber	0·21	1742	62·34
Entrance to tubes at back tube-plate	0·18	1292	49·21
Exit to tubes at front tube-plate	0·18	662	..
Funnel	0·15	572	32·81

The grate area in the above Table is taken as unity.

The following Table gives sections of air passages for other classes of boilers:—

—	Dupuy-de-Lôme. Direct tube-boiler.	Torpedo-boats 105-114. Locomotive boiler.	Horizontal Donkey boilers.	Bigot boiler.
	Sq. Ft.	Sq. Ft.	Sq. Ft.	Sq. Ft.
Ashpan doors	2·77	2·85	2·21	2·63
Air-passages through grate	3·30	5·56	3·42	5·59
Area above bridge	2·54	3·98	1·93	4·24
Area through tubes	2·29	1·31	2·50	3·25
Smoke-box	3·19	3·75	5·23	5·03
Funnel	1·84	1·31	1·62	1·50
Grate surface for one boiler	50·16	27·99	7·10	2·42

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In tubulous boilers the section for the gases is generally very large where the gases leave the grate. Baffles are often employed to reduce the section and increase the length of the course of the gases through the nest of tubes. Even with natural draught the gases sometimes reach the funnel too quickly. The bottom of the funnel, which, under these conditions, is at a temperature of about 932° Fahr., becomes a dull red, and greatly increases the draught; this gives rise to the entry of an excess of cold air, and thereby reduces the efficiency of combustion. In a boiler when the gases have too short a course, too high a funnel may lead to bad combustion, but in general it is advisable to have a high funnel.

32. *Height of Funnel.*—For a long time the regulation height given to funnels was 52½ ft., and the stokehold gratings for the access of air to the furnaces were about three times the area of the ashpits.

About twenty years ago it was first noticed that the draught was improved by increasing the height beyond that named above, more especially if the funnel had a casing used for the ventilation of the ship. It was thus in employing a double casing for the ship's ventilation that the expediency of increasing the height of the funnel of the old boilers was discovered.

In practice, the height of the funnel depends largely on the height of the upper deck and the class of vessel. On a cruiser, when the flying deck is about 33 ft. above the grates, the funnel may have a total height of 69 ft. above the grates. On the *Columbia* and *Minneapolis* the funnels are 98½ ft. high, though only having a height of 20 ft. above the upper deck. On a gunboat, when the upper deck is only 10 ft. above the bars, a height of 40 to 50 ft. might seem excessive to anyone not conversant with the exigencies of the case. On smaller craft, such as torpedo-boats, the funnel is never sufficient for the draught, and forced draught has always to be resorted to.

The use of protective decks, where all openings are reduced to a minimum, has so diminished the section allowed for the passage of air to the stokehold as to render combustion at natural draught incomplete whatever the height of the funnel.

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§ 4. FORCED DRAUGHT.

33. *Early Applications of Forced Draught.*—For a long time only natural draught was known. The height of the funnels gave sufficient draught to ensure a combustion equal to that of an ordinary land boiler, and suited to the requirements of the service.

The adoption of surface condensers prohibited the use of the only then known method of forced draught, namely, that used on locomotives; but on small boats the exhaust was used, as in the locomotives, to increase the draught.

The great utility of having some method whereby the intensity of the draught could be raised and a good combustion ensured at all times, had for a long time been recognised. Trials were made at an early date in America, where the anthracite coal used necessitated a good draught. Stevens tried various systems, from 1830 to 1850, of induced and forced draught. In 1861 Isherwood fitted eighteen gunboats with closed stokeholds.

In 1866 the wooden frigates sailing under the American flag had centrifugal fans blowing into the ashpans. In 1870 the Author proposed forcing air into the funnel in order to obtain a good draught, *i.e.*, to be able to burn easily up to 20 lbs. of coal per square foot of grate under unfavourable circumstances.

34. *The Bourdon-Thierry System.*—Among the older arrangements, that of Bourdon—which was considerably improved upon by Thierry—may be mentioned. It was tried in the French Navy in 1859, but had for its object rather the improvement of the efficiency of combustion than the creation of forced draught properly so called. The arrangement consisted of a ring of steam jets placed above the fire-doors and blowing steam along the grate. The stirring of the flame with the mixture of air, and the gases resulting from the decomposition of the steam, rendered combustion nearly complete before the hot gases were cooled down by contact with the heating surfaces.

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M. Aurous modified this system by causing jets of steam, arranged as ejectors, to draw in a certain amount of air above the grate, thus ensuring similar advantages to those obtained by forced draught.

The Bourdon-Thierry system was used in France from 1860 to 1870, but was then abandoned in consequence of M. Joessel having experimentally demonstrated that upon return tube-boilers it diminished rather than increased the efficiency of the fuel, and consequently the evaporative power of the boiler.

The adoption of tubulous boilers in which the course of the

SAVOIE.

BOURDON-THIERRY APPARATUS AS APPLIED TO BOILERS.

Front view.

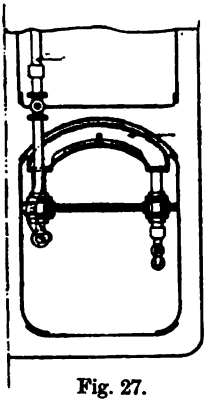

Fig. 27.

Longitudinal section through furnace.

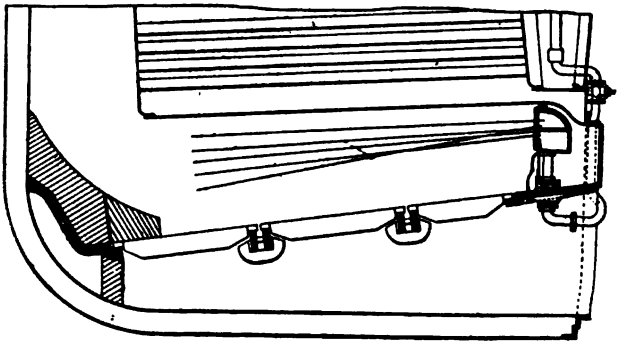

Fig. 27A.

gases is generally short, gave rise to a new application of the Bourdon-Thierry apparatus. In the Belleville boilers, where, with a good natural draught, it was found difficult to burn from 20 to 22 lbs. per square foot of grate, with the aid of this apparatus 26 lbs. could easily be burnt. Jets of steam were forced in in two places simultaneously, in the funnel and above the grate. The need of economising fresh water in the tubulous boilers led to the introduction of air instead of steam.

35. *General Properties of Forced Draught.*—Forced draught is now becoming daily more general on account of two distinct

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and important results obtainable thereby, viz, firstly, that the boilers can be worked at their maximum evaporative capacity, sometimes, however, to their structural detriment, and secondly, that losses due to the funnel are reduced because, with forced draught, a larger proportion of the total heat contained in the gases is capable of extraction before they are discharged into the atmosphere.

The first trials made in the French Navy aimed at increasing the power. The attempts to increase the economy of combustion are of much later date, and have been mainly followed up in the mercantile marine.

36. *Steam Jets in the Funnel.—M. Joessel's Trials.*—In 1869 and 1870 M. Joessel made some trials at Indret on steam jets in the funnel, concurrently with two other systems of forced draught, a fan in the funnel and the closed ashpit system. His results with the fans do not call for any special remarks, but the trials with the steam jets may be referred to with advantage.

M. Joessel's experiments were carried out on a boiler with 14·53 sq. ft. of grate surface and a working pressure of 32 lbs. per square inch. The steam for the jets was taken from an auxiliary boiler with the same working pressure as the main boiler. The results are given in the subjoined Table :—

Coal burnt per sq. ft. of grate.	Amount of Steam			Steam per lb. of Coal	
	Produced.	Expended on the Jets.	Available for the Engines.	Produced.	Available for the Engines
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
20·17	167·9	0·00	167·9	8·32	8·32
22·90	185·0	0·00	185·0	8·08	8·08
24·27	196·7	4·94	191·76	8·10	7·90
27·3	222·7	15·92	206·78	8·16	7·57
30·3	..	26·91	..	..	7·30
34·13	..	40·63	..	8·23	..
37·92	313·3	54·36	258·94	8·26	6·83
40·96	339·3	65·35	273·95	8·28	6·69

This Table shows that when using steam jets the combustion per square foot can be raised to 40 lbs.

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Without steam jets, when burning 27·3 lbs per square foot, the evaporation was only 200 lbs. of steam instead of 222·7 lbs., thus showing that the forced draught improved the evaporative efficiency of the boiler. M. Joessel's experiments lead to the conclusion that improving the draught by means of steam jets in the funnel was to be the accepted method of forced draught, but the advent of the tubulous boiler prevented its realisation.

Steam could not be taken from the main boilers, and although a donkey boiler for supplying the steam jets might easily have been used on board, it does not seem to have been applied practically, except in the case of the *Hirondelle*, where an increase of 22 per cent. in the power of the engines was realised.

37. *Steam Jets in Ashpit. — Niclausse Apparatus.* — M. Niclausse has lately tried a system of steam jets in the ashpit. Two steam jets on the front of the boiler induce a current of air. The arrangement is shown in Fig. 28, and the results are tabulated below.

Grate surface, 11·62 sq. ft ; H.S., 561·3 sq. ft.; ratio, 1 to 48·3.

Length of trial . . .	4 hours	5 hours	4 hours	5 hours	5 hours
Combustion per sq. ft. of grate— lbs.	20·5	25·6	30·7	35·8	41
Pressure of steam at jets— lbs. per sq. in.	28·4	56·8	95·3	106·7	120·9
Air-pressure in ashpits— inches of water	0·12	0·2	0·27	..	..
Air-pressure in uptake— inches of water	0·45	0·46	0·39	0·43	0·43
Temperature of gases at top of funnel . . .	446° F.	482° F.	572° F.	662° F.	707° F.
Evaporation per lb. of coal	8·5	8·7	8·6	8·48	8·25
Loss of fresh water due to jets— per cent.	3·3	4	4·5	5	5·2

The coal employed was the ordinary Anzin coal, and the boiler pressure was maintained at 206 lbs. in all the trials.

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The quantity of steam used for the jets was determined, after the trials, by turning it into a bell-mouth coil surrounded by water, and measuring the water condensed, conditions similar to those obtaining during the trials being maintained.

When burning 40·6 lbs. per square foot, the consumption of steam was practically identical with that given by M. Joessel.

A notable feature of the trials was the entire absence of clinker; only incombustible ash remaining.

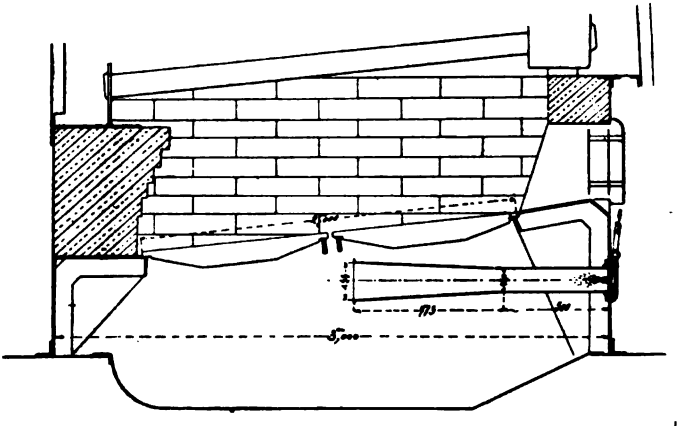

Fig. 28.

38. *Air Jets in Funnel.*—The first proposals to use air jets were negatived on the supposition that steam jets were much more economical. There is no foundation for this supposition. Steam can, on account of its lower density, compress to its own pressure a quantity of air equal to about four times its own weight. There may also be an advantage in adopting a pressure for the air jets different to that of the steam, and therefore, for economic reasons, their use may be advantageous.

When higher pressures came into vogue and forbade the use of fresh water, an experiment was decided upon on the *Fulminant* in 1875, and a preliminary trial was carried out a year later on the *Résolue.*

The boilers of the *Résolue* were of the ordinary cylindrical type, with a working pressure of 57 lbs. per square inch. The air-compressors were simple condensing engines consuming

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about 33·5 lbs. of steam per horse-power. The jets fitted to the base of the funnel had a constant cross section of $\frac{1}{10}$ sq. in. per square foot of grate. The air-pressure rose with the working of the engines; it varied from 2·12 to 10·2 in. of water.

The figures in the following Table, which are per square foot of grate per hour, have been calculated on the assumption that the blowers required 33·5 lbs. of steam per horse-power hour:—

Coal per Sq. Ft. of Grate per Hour.	Required for Blowers.		Total Steam produced per Sq. Ft. of Grate.	Steam per lb. of Coal	
	Horse Power per Sq. Ft. of Grate.	Lbs. of Steam per H.P. per Sq. Ft. of Grate.		Produced.	Available.
				Lbs.	Lbs.
19·8	0	0·0	167·3	8·45	8·45
26·3	1	33·5	216·2	8·22	8·09
28·8	2	67·0	230·1	7·99	7·78
30·7	3	100·6	239·3	7·79	7·49
32·6	4	134·1	248·4	7·61	7·23
34·6	5	167·6	259·9	7·50	7·06
36·7	6	201·1	269·8	7·36	6·85
38·5	7	234·6	274·9	7·14	6·58
40·3	8	268·2	282·4	7·00	6·39

The efficiency of the boiler of the *Résolue* decreased steadily as the draught increased, while in the experiments at Indret the efficiency remained nearly constant. This difference can only be put down to the arrangement of the boilers, and to inferior stoking. In order to compare air jets and steam jets as a means of increasing the draught, account must be taken of the amount of steam consumed at the same intensity of combustion. This gives 65·3 lbs. with steam as against 25·6 lbs. with air for a combustion of about 41 lbs. per square foot of grate, and therefore the steam jet requires 2·5 times as much steam to produce the same result.

The result obtained on the trials of the *Fulminant* in 1881, with a combustion of 27·57 lbs. of coal for 15·82 horse-power of the fans per square foot of grate, agrees with those obtained on the *Résolue*.

When comparing the effect of steam and air jets, the fact must not be lost sight of that the use of steam requires an

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expenditure of coal, which nearly doubles the consumption, in order to make good the loss of fresh water.

39. *Exhaust Fans in the Funnel.*—In 1876 very little attention was paid to fitting the draught-producing apparatus in the funnel, which, from a working point of view, is a very convenient arrangement. On the *Sfax*, although the boilers were designed to consume 28·7 lbs. per square foot of grate, as a matter of fact, never more than 23·7 lbs. of coal were actually burned, and the use of air jets was abandoned. Owing to the success of Mr. Thornycroft's first torpedo-boats, the system of forced draught with closed stokehold met with such a favourable reception that all other systems were for a long time neglected. It was a long time before it was recognised that this system, at its most effective rate of working, is not suitable to large vessels with tubular boilers, and that if kept within the necessary limits, it ceases to compensate for the inconvenience attending its use. The tendency at the present time is to revert to open stokeholds; this is a return, after twenty years, to a less powerful but more convenient method, to which the name of induced draught has been given.

Air jets may possibly be again adopted, but in the meantime a fan placed at the base of the funnel, and drawing the gases through the smoke-box, is now used. This arrangement was formerly suggested by Stevens, and was actually employed in 1876 on the *La Bourdonnais* by M. de Maupeou, who does not seem to have heard of Stevens' proposal.

M. de Maupeou tried both a fan and jets of compressed air at the same time on board the *Bièvre*; he compared the two systems by measuring the amount of work per square foot of grate required from each to give the same depression in the funnel. His results are given in the Table on page 69, from which it will be seen that the air jets consumed more power on the *Résolue* than on the *Bièvre* to produce the same draught.

The trials of the *Bièvre* show that a fan is more economical for pressures of 0·6 in. and over, but that the air jets have the advantage for pressures lower than 0·6 in. It is probable that the fan is markedly superior to the jets at all draughts when

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compressed air at high pressures, say of from 20 to 40 lbs. per square inch, is used, as has been lately resorted to in order to diminish the weight and space occupied by the compressors. Under these conditions, air jets have been found to be very costly on the *Léger*, the *Lévrier*, and on various vessels fitted with Belleville boilers.

By his experiments on the *La Bourdonnais*, M. de Maupeou established the inefficiency of fans in the funnel. Finally, he tried forcing the air into a closed stokehold, and found it more economical than the system of induced draught in the funnel.

40. *Closed Stokehold System of Forced Draught.—Application to Torpedo-boats.*—The closed stokehold system of forced draught consists in forcing air, by means of a fan, into a stokehold which has been hermetically closed, leaving the air no other exit than through the grates, and thence to the uptake. Having already been tried in 1846 by Stevens, applied a little later by a Dutch river steamboat company, and adopted by Isherwood on his gunboats, this system was definitely introduced into the navy by Thornycroft as a sequence to the introduction of the torpedo-boat.

In order to push the boilers of torpedo-boats, very much higher draughts have to be employed than on the *Résolue*, which never exceeded $\frac{3}{4}$ in. of water for a combustion of, at the most, 41 lbs. per square foot of grate. From the first Mr. Thornycroft aimed at obtaining the same results as realised on locomotives, which burn 164, 184, and even 225 lbs. of coal per square feet of grate at a draught of 10 in. of water. Adopting a boiler of similar construction, he forced in air by means of a fan until the pressure rose to 7 and even 8 ins. It was apparent, however, that this was higher than was necessary. The closed stokehold system has not in any degree the valuable features of induced draught, as met with on locomotives, where the combined effect of the induced draught and the influence of the speed of the train on the supply of air to the ashpan varies directly with the speed on the engine itself, and regulates the rate of production of steam in direct proportion to its consumption.

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The want of head-room in a torpedo-boat will not permit of the very high furnaces that are used on locomotives, or a thickness of fire in keeping with the powerful draughts employed on them. The very strong currents sweeping through a thin fire cooled down the gases and carried with them particles of burning coal instead of cinders. The more violent the current of air the larger was the total amount of coal put on; but the draught corresponding to the maximum evaporative power of the boiler was often exceeded. Little is known about the working of the fans at this period, but 1·83 I.HP. per square foot of grate would appear to have been reached and even exceeded.

The reaction against the overworking of torpedo-boat boilers has been slow in setting in. A combustion of 123 lbs. of coal per square foot of grate per hour on board the *Téméraire*, 130 on the *Défi*, and 154 on the *Alarme* has been obtained with a consumption equalling 4·7 lbs. of coal per indicated horse-power, which is very nearly the consumption of non-condensing locomotive engines. The excessive consumption was, moreover, one of the least objections to this uneconomical working; the principal one was the frequent failures while under steam, mainly at the joints between the tubes and tube-plate, and the rapid wear resulting from fatigue of the whole boiler. Finally, the physical standard for stokers in the navy does not furnish men capable of standing the frequent charging of the fires that is necessary with such a high rate of combustion. Moderation is, consequently, a necessity. Upon the fifteen 50-ton torpedo-boats fitted with the locomotive boiler, which were tried in 1890–91, the combustion did not exceed 72 lbs. of coal per hour, though the air-pressure was still about $5\frac{7}{8}$ ins. Upon the six of the above boats that were built by M. Normand, the maximum rate of combustion on the trials was between 53 and 63 lbs. per square foot of grate with, at the most, only 4 ins. of air-pressure. Under these conditions the consumption of coal per horse-power was not more than 2·23 lbs., and at times only 2 lbs.; the fan power was about 1·3 HP. per square foot of grate.

A consumption of 72 lbs. per square foot of grate per hour is

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the limit adopted on the new torpedo-boats fitted with tubulous boilers of the Du Temple or similar types. This rate of consumption is obtained, while keeping the fires thinner than formerly, with air-pressures below, or very little above 2 ins. of water, except in the case of the *Forban*, upon which an air-pressure of above 4 in. was allowed.

——	——	Air-pressure in Inches.	Consumption per Sq. Ft. of Grate.	Consumption per Horse-power.
			Lbs.	Lbs.
Flibustier .	14 knot trial .	0·25	15·5	1·17
	full speed trial .	2·1	63·4	1·59
Ariel . .	14 knot trial .	..	7·11	1·08
	full speed trial .	1·25	71·3	1·80
Forban .	14 knot trial .	..	7·06	0·86
	full speed trial .	4·75	63·9	1·36

41. *Closed Stokehold System of Forced Draught Applied to Large Ships.*—From the moment of its appearance on the first torpedo-boats, the success of the closed stokehold system of forced draught gave rise in France to a number of schemes for its general application; it was proposed by this means to increase the power of existing boilers, and to reduce to about half the weights of the boilers in the boats then under construction. M. de Maupeou, who played a prominent part in the movement, examined carefully, as has already been seen, the comparative merits of the different systems put forward. He found that the closed stokehold showed a marked economy over the other systems, even when compared with a fan placed in the funnel. This is shown in the following Table taken from his reports:—

Systems of Forced Draught.	Power of Fans per Square Foot of Grate for the following Air-pressures.			
	0·6 in.	0·78 in.	1 in.	1·18 in.
Closed stokehold . . .	0·92	2·29	2·02	2·75
Air jets in the funnel .	1·28	3·21	5·13	7·34
Induced draught . . .	1·83	2·93	3·67	5·23

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As the result of these trials the closed stokehold system was definitely adopted upon the *La Bourdonnais* in 1876, and subsequently upon several other cruisers. The British Admiralty, however, did not adopt the system until 1882, when it was fitted on board the *Conqueror* and *Satellite*.

Those responsible for the designs of new boats at first accepted with caution the means of lightening the boilers which thus presented itself. As was stated above, the *Sfax*, which was intended to burn 29 lbs. per square foot of grate, only burnt 24 lbs.; while on the *Tage* the highest consumption obtained was 30 lbs. per square foot of grate. The system was applied to the old type of return-tube boiler, which was well fitted for it, being strongly constructed and well adapted to utilise the heat produced. The results of the trials were encouraging, the only objections being the complications introduced by the necessity of closing all the outlets with double doors, and the uneasiness of the stokers at being shut up in the closed stokeholds.

Emboldened by the success of these trials, the constructors pushed the consumption up to 51 lbs. per square foot of grate. At the same time they abandoned the return-tube boiler in favour of the direct-tube type, which is more liable to failure, even at ordinary draught, and much less capable of sustaining such high rates of combustion. To this period belong the trials of the ironclads *Hoche*, *Marceau*, and *Magenta*, on which the consumption was equal to 50 lbs. of coal, the power required for the fans amounting to 0·27 HP. per square foot of grate. Following these came the trials of the gunboats of the *Grenade* type, in which 51 lbs. of coal were burnt per square foot of grate, the fans requiring 0·24 HP., and in particular the trials of the small cruisers of the *Forbin* type, upon which the combustion was pushed up to 66 lbs. at the cost of repeated accidents, bringing about the rapid destruction of the boilers.

The three cruisers, *Troude*, *Lalande*, and *Cosmao*, may be cited as examples of boats which gave, without any mishaps worth mentioning, successful results on their trials. The following are the data obtained from the trials, the horse-power

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required for the fans being calculated from their revolutions, which were 350, and the mean pressure on the pistons, which was equal to 57 lbs. :—

——	Horse-power of Fans per Sq. Ft. of Grate.	Pressure in the Stokehold.	Pressure in the Smoke-box.	Total Draught.	Combustion per Sq. Ft. of Grate.
		In. of Water.	In. of Water.	In. of Water.	Lbs.
Troude . .	·366	1·30	0·43	1·73	58·40
Lalande. .	·366	1·22	0·43	1·65	58·26
Cosmao . .	·366	1·02	0·49	1·51	52·70
Mean . .	·366	1·18	0·45	1·63	56·45

The gain in power and speed was as follows :—

——	Natural Draught.				Forced Draught.			
	F Horse Power.	V Knots.	M	C Consumption per I.HP.	F Horse Power.	V Knots.	M	C Consumption per I.HP.
				Lbs.				Lbs.
Troude .	3439	17·56	8·156	1·97	6351	20·91	7·933	2·85
Lalande .	3666	17·31	7·867	1·90	6447	20·69	7·783	2·92
Cosmao .	3596	17·37	7·940	1·91	6301	20·60	7·816	2·64
Mean .	3567	17·41	7·987	1·92	6366	20·73	7·844	2·80

It will be seen that for an increase in speed of a little less than one-fifth, the consumption of coal per horse-power increased one-half.

About the same time, in the trials of the *Yayéyama* in February, 1891, the speed was raised from 18·4 to 20·9 knots, and a still higher speed could have been obtained had not the fear of a breakdown prevented the fans from being run at full speed.

The closed stokehold system was very generally employed

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about this time by most naval powers, until the results of actual working shattered the hopes based upon the early trials.

One serious inconvenience had already been brought to light by the trials, and this was the increase in the consumption of coal per horse-power in boilers unfitted for forced draught. An increase of 50 per cent. in the coal consumption rendered forced draught particularly unsuitable to ships of limited bunker capacity. Great disappointment was experienced in the behaviour of the boilers in actual practice. It was found that failures, principally leaky tube-joints and the dropping of the furnace crowns, increased to an alarming extent. The dangers were by no means compensated for by the expected increase in power, as ordinary stokers were incapable of realising it. The only salient feature that remained was the complication introduced into the service by the hermetic closing of the whole stokehold by means of air locks and double doors. It is not difficult to realise the bitterness with which the closed stokehold system was characterised as a "diabolical invention."

At the present day, by an extreme reaction, the use of excessive forced draught has been limited to torpedo-boats and destroyers, and the maximum combustion for battleships and cruisers has been fixed at about 30 lbs. per square foot of grate. The result of this is a loss of one knot in the estimated speed of the cruisers *Blake* and *Blenheim*, while in the French Navy, in order to maintain the same power for the estimated weight of the boilers, or the same weight for an estimated power, the extreme step was taken in 1892 of abandoning the use of tubular boilers before it had been definitely settled by what type of tubulous boiler they should be replaced.

The French Navy at the present day has in use a large number of tubulous boilers of limited or free circulation, which, on account of the arrangement of their furnaces and water-tubes, are not considered suitable for the employment of very high rates of forcing. Tubulous boilers of accelerated circulation, which are, on the contrary, capable of being energetically forced, were in 1895 almost exclusively confined to torpedo-boats. If this latter type of boiler has sufficient endurance to warrant its application to large vessels, it will solve the two problems of

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lightness and forced draught; but it would be as well to use a moderate rate of draught to begin with.

The mercantile marine, which still remains faithful to the marine type of tubular boiler, has also taken up the subject of forced draught. The conditions of the problem are, however,

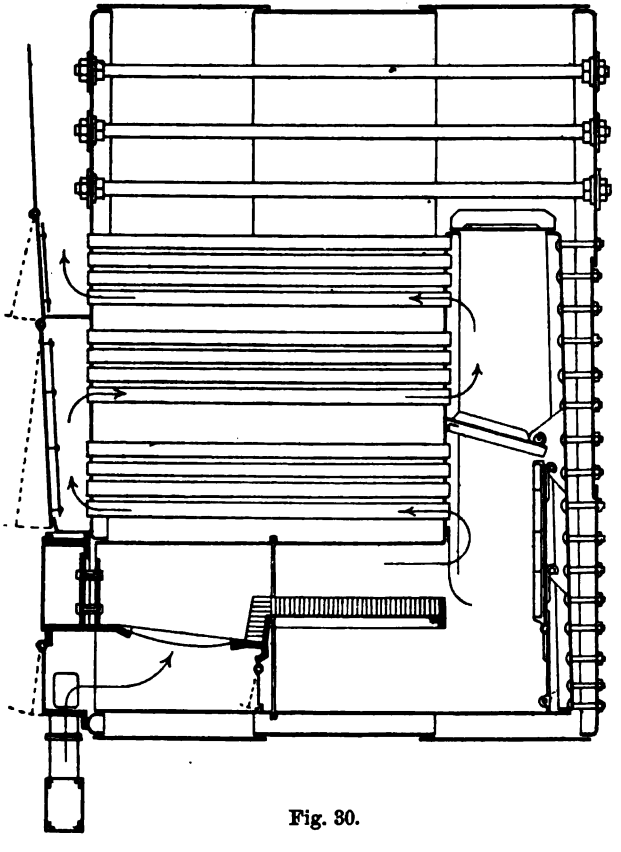

Fig. 30.

considerably modified, as economy of fuel is sought for rather than lightness of boilers, and the complications of air locks, etc., arising from the use of the closed stokehold system of forced draught must be suppressed as far as possible.

42. *Closed Ashpit System of Forced Draught.*—The system

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of forced draught most generally employed in the merchant service is that of the closed ashpit, in which the fans, instead of forcing air into a closed stokehold, force it directly beneath the grates.

In this system, the pressure of the air in the interior of the furnace being higher than in the stokehold, the fire-doors must be in the passage leading the air from the fans, in order that the air may pass in through them above the grates. Moreover, in order to avoid the return of flame into the stokehold, the draught must be interrupted each time a fire door is opened. The air feed is also usually interrupted when the ashpit doors are opened, but this is merely to prevent an inconvenient escape of air into the stokehold. The air feed is usually automatically cut off whenever the furnace doors are opened.

§ 5. FORCED DRAUGHT AS A MEANS OF INCREASING THE HEAT EFFICIENCY.

43. *Forced Draught as a Means of Economising Heat.*—Natural draught, considered as a means of imparting to the column of gases the movement necessary to produce combustion, forms a very uneconomical motor. Supposing the gases to pass out at 522° above the temperature of the air, the loss of heat is 2,400 B.T.U. per pound of coal, exclusive of the latent heat of the steam contained in the smoke; the only result obtained is a speed of 32·8 ft. per second imparted to a weight of gas composed of 19 lbs. of air to 1 lb. of coal—20 lbs. of gas in all; the energy per lb. of coal is given by the expression—

$$\tfrac{1}{2} \times \frac{20}{32{\cdot}2} \times 32{\cdot}8^2 = 334{\cdot}2 \text{ foot-pounds},$$

that is to say, 0·00017 HP. On the other hand, an expenditure of 2,400 thermal units corresponds to 0·15 lb. of coal per hour. The expenditure of heat per horse-power is therefore enormous. In other words, the mechanical efficiency of natural draught, regarded as a means of propulsion, is extremely small, practically *nil*, and all that can be otherwise

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used of the 18·9 per cent. of the total heat lost in producing natural draught is a net profit.

The heat of the gases can be made use of in four different ways :—

1. By increasing the length of passage through the water.
2. By superheating the steam produced, by means of an arrangement fitted to the boiler.
3. By heating the feed water.
4. By heating the air necessary for combustion.

The water in the boilers, or the steam produced, cannot cool down the gases much below 570° through a metal plate, since the temperature of steam at the pressures now in use is very nearly 400°. The various attempts made to superheat the steam have always failed, even when the temperature of the steam was only 250°, on account, no doubt, of the bad conducting power of dry steam.

Audenet's arrangement for increasing the production of saturated steam by lengthening the course of the gases through the boiler has been abandoned. There remains, then, only the heating of the water and the air, which, in theory, would allow of the hot gases being cooled down to about the temperature of the surrounding air. The hot gases would be cooled down to the inlet temperature of the water or air, while the air or water would be raised to the initial temperature of the escaping gases. As regards the air, this might be feasible, but with the water it is not advisable to commence evaporation too early, as it might reverse the direction of circulation in the feed-heater.

44. *Feed-Water Heating.*—The weight of water evaporated in a well constructed boiler is equal to, in round numbers, half the weight of the burnt gases, the specific heat of the water being nearly four times that of the gases. Neglecting radiation, the rise in temperature of the water in a feed-heater would be equal to half the decrease of temperature of the gases. This elementary reasoning shows that the heating of the feed water provides a means of utilising all the heat that the gases can be deprived of, at the high pressures at present in use, which allow of a drop in temperature of 270° or more for heating the water.

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Theoretically, there is nothing to prevent the gases being cooled below 212° and thus condensing the steam.

Numerous attempts have been made to heat the feed water by means of the escaping gases. Indeed, in some recent tubulous boilers, such as the Oriolle, Towne, Babcock, etc., a coil has been fitted, forming an integral part of the boiler, for this purpose. The very first Belleville boiler had a feed-water heater, and the latest form of this boiler has a greatly improved apparatus of the same kind. Generally speaking, the heaters have been of small size, not very efficient, and have not necessitated the introduction of forced draught. As long as the temperature of the water keeps below boiling-point, and the heater is not subjected to internal pressures, it is of very simple construction. There is a distinct saving in even a slight heating of the feed water, and the efficiency of the boilers is increased by accelerating the formation of steam bubbles whereby the general circulation of the whole boiler is improved.

The heating of the feed water by means of the escaping gases has been tried by Ebenezer Kemp, of Glasgow, who has given more attention to the subject than almost any other inventor.

In constructing several boilers for the Clan line, from 1879 to 1886, Mr. Kemp used small coils as feed-water heaters, having an area equal to one-tenth that of the heating surface of the boiler; the gases were only slightly cooled, and the natural draught, the only one employed by him, was not in any way affected. The consequent heating, as the temperature of the water was only raised by 40° Fahr., hardly paid for the cost of the installation.

In 1886, on the *Bléville*, built for a Havre firm, Mr. Kemp first made a serious attempt to solve the problem of thoroughly cooling the escaping gases. He fitted feed-water heaters, resembling small tubulous boilers, having a collective heating surface double that of the boilers themselves, and also an exhaust fan at the base of the funnel.

A trial was made in Glasgow Harbour, with the result that the escaping gases were cooled down from 1,040° to 356° = 684° Fahr., while the temperature of the water was raised

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360° – 120° = 240° Fahr. The hot gases were therefore taken at a very high temperature, and were discharged at a temperature 236° above that of the incoming water; 3,283 thermal units were abstracted from the gases per pound of coal consumed (20 × 684 × 0·24 = 3,283), of which 2,394, at the most, were absorbed, and 889 were lost by radiation or conduction in the heater.

Trials with natural draught were made both in harbour and at sea.

In harbour it was found that 1·18 lbs. of coal per horse-power were consumed, being 14·9 lbs. per square foot of grate, a very good result for a triple-expansion engine working at 160 lbs. pressure. The hot gases had an initial temperature of 644°, which was reduced to 302° Fahr.

At sea, on a voyage from Glasgow to Havre, the consumption of coal was never below 1·41 lbs. per horse-power. The idea was, however, soon abandoned, for it was found that the heater tubes became perforated, and that, owing to the formation of steam chambers, they sometimes gave out at the joints. The heaters were first taken out, and subsequently the boilers themselves, as they were found not to be powerful enough alone; these were replaced by larger boilers, weighing as much as the first ones and their feed-water heaters put together.

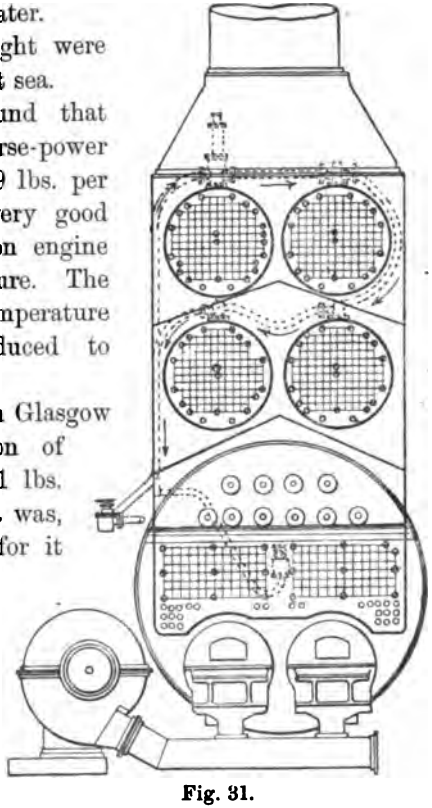

Fig. 31.

Mr. Kemp then adopted a new arrangement. In 1888, on the *Caloric*, forced draught was used on the closed ashpit system. The feed-water heaters consisted of four small

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cylindrical boilers, filled with water, and fitted with tubes for the gases to pass through. The gases, after passing through the lower group of heaters, returned through the upper one prior to reaching the funnel; they had an initial temperature of 680°, of which they lost 234° in the lower, and 207° in the upper group, finally emerging at a temperature of 239° Fahr. The water, on the other hand, circulated through the four heaters successively, gaining about 36° Fahr. in each.

It follows, therefore, that the hot gases lost 2,017 thermal units per lb. of coal, of which 1,440 were taken up by the water, and the balance, 677, was lost by radiation, the weight of water and gas being taken as before.

The heating surface in the *Caloric* heater is, relatively, rather greater than that on the *Bléville*, and the heating surface of the boiler itself is considerably greater; the principal data in the two apparatus and results of the harbour trials are given in the following Table:—

	Grate Area.	Heating Surface.		Ratio.		Cooling of the Gases.	Heating of the Water.
		Boilers.	Heaters.				
	G	S	S′	$\frac{S}{G}$	$\frac{S'}{S}$	ΔT	Δt
	Sq. Ft.	Sq. Ft.	Sq. Ft.				
Caloric .	38·47	1612·2	3498·3	42	2·17	441° F.	144° F.
Bléville .	70·72	1768·0	3390·7	25	1·92	396° F.	153° F.

The apparatus on board the *Caloric* had a practical trial while the vessel was doing between 38,000 and 40,000 miles a year; the hourly consumption per horse-power was 1·27 lbs.; the daily consumption was about 9 tons, while on the steamers of the same line not provided with feed-water heaters, the consumption was about 11 tons, which gives a saving of about 18 per cent. The working appears to have been satisfactory. At the commencement it was reported that some of the tubes showed signs of corrosion near the feed-water inlet, which was in no way surprising as the water at that time was not purified in any way, or neutralised by the admixture of alkaline sub-

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stances, and that mineral oil was used for the internal lubrication of the cylinders, and tallow for the stuffing boxes. The corrosion of the heater tubes, however, saved those of the boiler proper.

The weight of the heaters on the *Caloric* cannot have been less than 57·4 lbs. per square foot of grate, or say about one-fifth of the total weight of the boilers.

Mr. Kemp retired from practice in 1890, and died soon after. Since then the application of his principle appears to have been suspended, and the tendency is rather towards the use of steam for heating the feed water. It would, nevertheless, appear as if a return were going to be made to heating water by means of hot gases. For instance, in the case of the latest Belleville boilers, heaters similar to the boilers themselves have been placed in a large chamber at the base of the funnel, and the two upper rows of the main boiler tubes being taken out in order to reduce the weight, an installation with 395 sq. ft. of grate is only increased in weight by 6 tons.

This system, which has recently been tried in the British Navy, has been applied on two steamers of the Messageries Maritimes, and a saving of 20 per cent. in coal consumption is to be expected if the results of the trials on shore are substantiated.

Some data with regard to this latest form of Belleville boiler, which has recently been fitted to H.M.S. *Diadem*, will be found on page 238. Sir John Durston, the Engineer-in-Chief of the Navy, states that the fitting of the economiser has been attended with beneficial results.

45. *Howden's, and Ellis and Eaves' Forced Draught Systems.* —In the apparatus used for heating the air prior to combustion, very thin tubes are used, because they are not subject to any pressure. The cooling of the gases and the heating of the air must naturally be equal to one another, except for the losses in the heater. As there is no limit to the degree of temperature to which the air may be raised, so there is nothing in theory to prevent the complete cooling of the escaping gases. It would appear that water, owing to its high conductivity, is infinitely better adapted than air to abstract the heat from the gases, or in other words, that air would require a very much larger

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heating surface to do the same amount of work. This view is not, however, confirmed by practice. With the same heating surface the temperature has been raised 180° with air, 144° with water. At the same time, it is much more difficult to ascertain the temperature of heated gases subject to radiation than that of water.

The results of heating the air are somewhat complex because the combustion of coal in hot air is much more rapid and complete than in cold air.*

It has been asserted, with some appearance of truth, that a rise of 180° Fahr. in the temperature of the air is followed by one of 360° Fahr. in that of the fire, owing to the more complete chemical combination; and further, by shortening the grate, all risk of cooling prior to its reaching the tubes is avoided.

Mr. J. Howden has made a special study of the heating of the air for combustion. He began in 1859 by utilising the steam from the cylinders. In the process of condensing steam by cold water there is a much greater loss of heat than that which takes place by the funnel, and, up to the present, no remedy has been discovered for this evil. In 1860 Mr. Howden took out a patent for a condenser in which air was used to cool the exhaust steam. This apparatus was not applied to marine boilers: it might, perhaps, be worth a trial on locomotives on which water for condensing purposes cannot be carried.

Mr. J. Howden turned his attention to heating the air for the furnace by cooling down the escaping gases. His apparatus was successfully applied on the *City of New York* in 1884, and the results were encouraging from the first. He estimated that the temperature of the air was raised to 184° Fahr. on this steamer; on the *Indiana*, another steamer of the American line, with a greater heating surface, the rise appears to have been 270°, while the temperature of the escaping gases was 455° Fahr. Under forced draught 22·03 HP. per square foot of grate was obtained. The *Illinois* and the *Pennsylvania* have been similarly fitted to the *Indiana*.

* The amount of heat produced by combustion, on the other hand diminishes as the temperature increases; it becomes *nil* at a temperature great enough to dissociate the products of combustion.

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Anticipating the success of the *Saint Louis* and *Saint Paul*, built by Messrs. Cramp, Mr. Howden has guaranteed a consumption of only 1·23 lbs. per horse-power, or a development of 22·03 HP. per square foot of grate. Since then 68 lbs. per square foot of grate have been burnt, and 25 HP. per square foot of grate developed without difficulty.

Howden's system has been adopted on the *Celtic*, *Majestic*, and *Teutonic*, of the White Star line, and on the *Sylvania* of the Cunard line. The Peninsular and Oriental Company, the Allan and the Clan lines, have also fitted some ships with it.

On the large cruisers and on the ironclads of the American Navy the ordinary closed stokehold is employed, and the gases are not cooled; but Howden's system is in use on the smaller vessels, *Detroit*, *Montgomery*, *Marblehead*, *Concord*, *Bennington*, and *Bancroft*. It has also been adopted by the Dutch and other foreign governments.

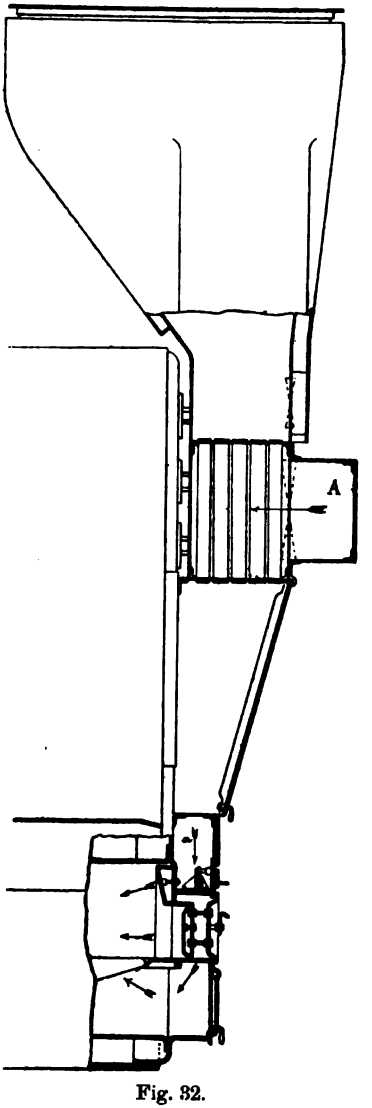

Fig. 32.

Figs. 32 and 32A show the arrangement on the *Indiana*. The air is blown into the ash-pit by a fan, and passes through the chamber A, where it circulates round a bundle of vertical tubes, through which the hot gases pass. Special attention is

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drawn to the efficient manner in which the air is delivered to the ashpits and furnaces.

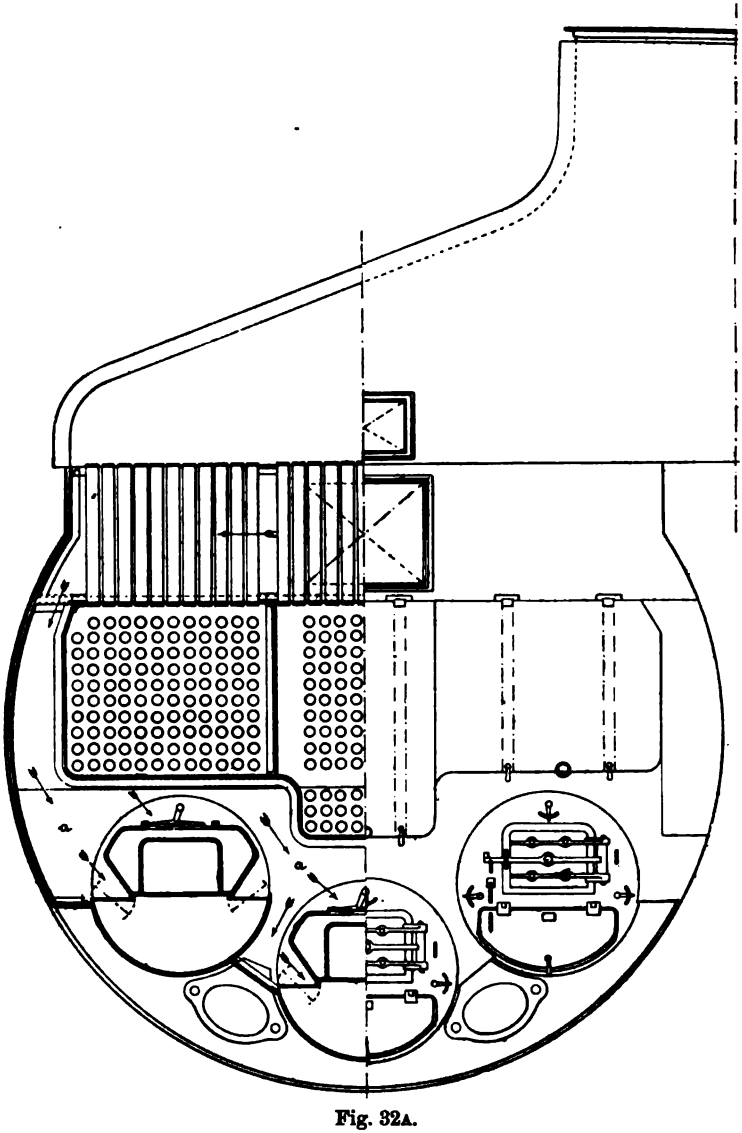

Fig. 32A.

The air is supplied to each furnace from a chamber A

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attached to the front of the boiler, which communicates with the passages for the delivery of the air by means of a single opening in which a damper is fitted. From the chamber A the air finds its way directly into the ashpit and into the side spaces of the furnace, and by the holes in the double door to the furnace itself.

Under the Howden system it has been found necessary to raise the level of the grates at the back of the furnace when the combustion is intense, that is, when it approaches 60 lbs.

The heating of the air does not necessitate its being forced into a closed ashpit; it is quite feasible to force the draught by using an exhaust fan at the base of the funnel, which thus constitutes an induced draught on a closed ashpit system. This is practically the system brought out by Messrs. Ellis & Eaves, of John Brown & Co., of Sheffield.

The Ellis system was first tried on the shop boilers at the works of Messrs. John Brown & Co.; it was then adopted on the Shire line in the *Perthshire*, *Buteshire*, and *Banffshire*, and on the *Berlin*, *Southwark*, and *Kensington*; it will therefore soon be possible to compare the Howden and Ellis systems on boats of the same line.

The Ellis heater is fixed on the top of the boilers, and is divided into two parts, separated on the front by the smoke-box and at the back by the funnel; the hot gases which pass outside the tubes have therefore to take a somewhat complicated course round four right-angled bends; the passage of the air to be heated on its way to the ashpit is, on the contrary, very simple. The distribution of the air in the ashpit and furnace is similar to Howden's, except that it can be controlled by separate dampers so as to give more or less air over or under the grate, according to the quality of coal used (Figs. 33 and 33A).

The advantages of the Ellis system lie in the general convenience of the suction process, to which may be added the avoidance of jets of very hot air ejected into the stokehold. The pressure in the air and smoke passages being everywhere less than in the stokehold, the want of tightness in the joints is unobjectionable, indeed some holes are purposely left so as to create a draught in the stokehold. The furnace and

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ashpit doors may be opened without having to close any dampers, and by opening them the intensity of the combustion is increased, thus compensating for the cooler air admitted, therefore — so the inventors affirm—the cooling of the boiler while firing is taking place is very slight.*

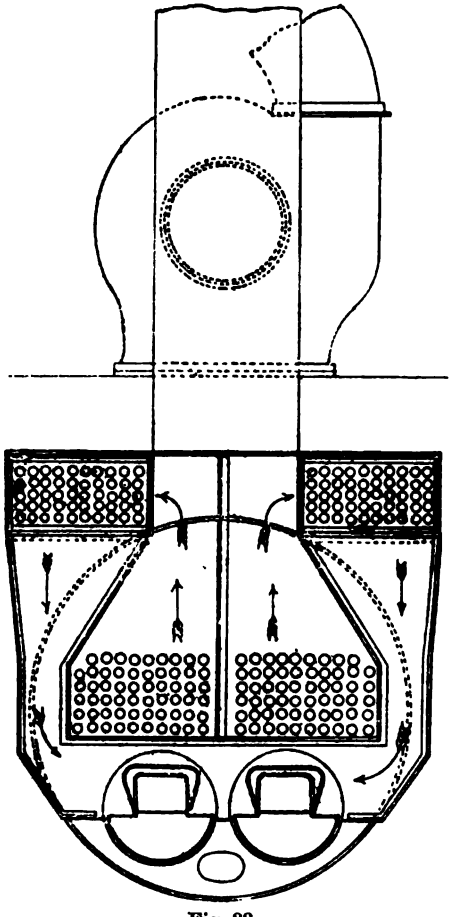

Fig. 33.

The drawbacks to Ellis's system are those inherent to any system of induced draught, that is to say, the low efficiency of a fan working in hot gases of a low density, and, in spite of the sudden cooling, of a less specific gravity than the surrounding air. The air to be heated has a tortuous passage round no less than nine right angles and drops 3·54 ins. in pressure before reaching the grate. While passing through the fire-grate another 0·35 is lost, and by the time the hot gases reach the fan they have lost

* On this point stress might be laid on the results of a comparison which was made at Brest, on a Godard boiler, between the draught with closed stokehold and the closed ashpit system. With the latter, pressure dropped 15 lbs. on opening the doors; with the former there was no change. As regards the flow of air to the furnace, Ellis's induced draught has a similar effect to that of the closed stokehold.

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a further 0·55 in. Messrs. Ellis & Eaves obtain from the fan in their shop boilers a total pressure of 4·5 ins.,

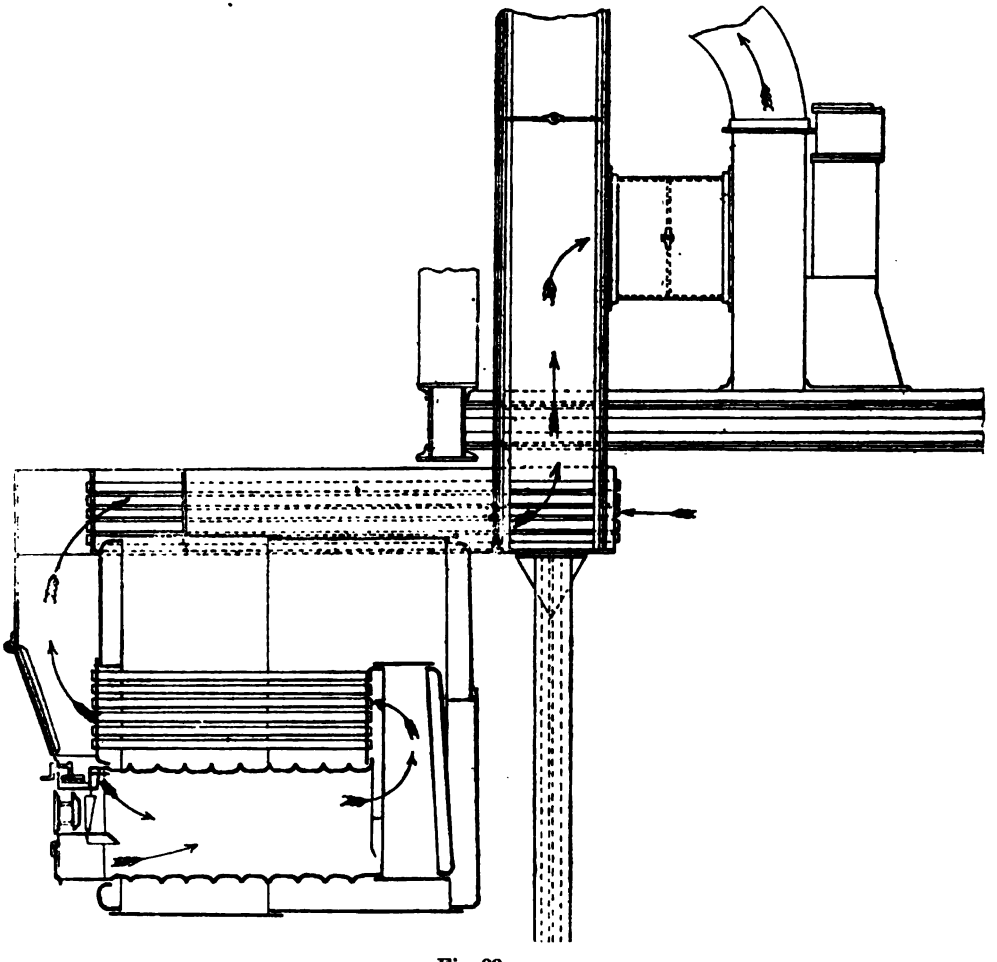

Fig. 33A.

while developing 0·3 HP. per square foot of grate. Every boiler with two furnaces requires a fan at least 5 ft. 6 ins. in diameter. Marine boilers, it is true, with heaters more advantageously placed, require a smaller draught, viz., 3·46 ins. on the *Berlin*, 2·91 ins. on the *Southwark*, and only 1·73 ins. on

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the *Perthshire*. The size of the fans is large, viz., 7 ft. 6 ins. on the *Berlin*, and 8 ft. on the Shire line. It is evident that it would be difficult to find room for fans of this size at the base of the funnels of ironclads.

The *Perthshire* and the *Buteshire* have made several voyages to Australia, burning from 25·8 to 31·1 lbs. per square foot of grate (or a mean of 28·45 lbs.), while consuming 1·36 lbs. per horse-power of the main engines. If it be admitted that with the usual forced draught in closed stokeholds, and without any heating of the air, it is necessary to burn 1·5 lbs. to obtain 2·1 HP. per square foot of grate, the saving effected in fuel by heating the air amounts to about 15 per cent.

Messrs. Ellis & Eaves attribute a great part of the saving effected to the use of Serve tubes.

Messrs. Ellis & Eaves are now putting forward a modification of their earlier arrangement, which embodies several improvements, and from which they expect to obtain more favourable results. (Fig. 33B.)

Neither Mr. Howden nor Messrs. Ellis & Eaves have given the weight of their respective heating apparatus. The author calculates that for a heating surface twenty-three times the grate area, it might be taken at 0·059 ton per square foot of grate exclusive of the fans.

From all this it will be gathered that forced draught has been designed and applied in two totally different ways; the one on warships, where the object is to develop the greatest amount of power during a short time, the other on mail steamers, where it is most important to use as little fuel as possible during a long voyage. The different manner in which the two problems have been solved might at first sight appear to be in accordance with the circumstances surrounding each case. When, however, the question of weight, and also that of immunity from accidents—which is as important for warships as for the merchant service—has been thoroughly gone into, the solution arrived at is not so satisfactory as would appear at first sight.

Supposing 46 lbs. to be the maximum weight of coal that can be burnt per square foot of grate in boilers of a given type, and

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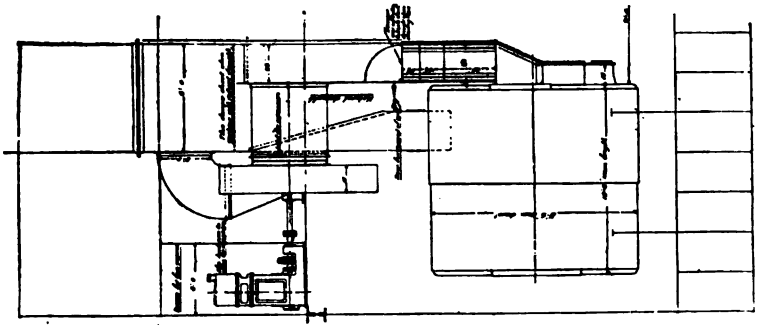

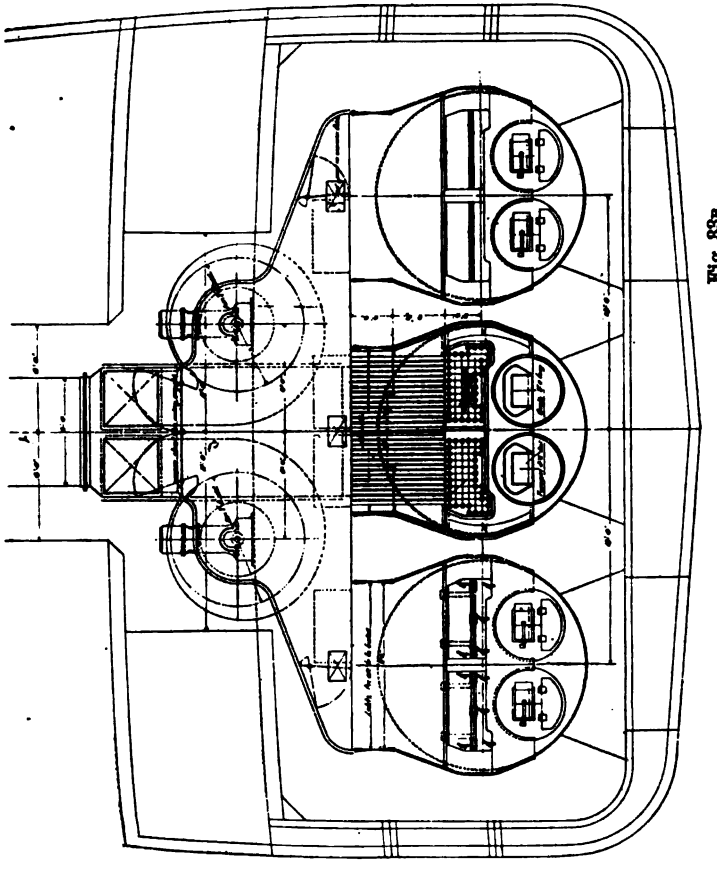

Fig. 83b.

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that by heating the air the consumption of fuel may be reduced by 10 per cent., say from 1·56 to 1·41 lbs. per horse-power; it is evident that for a given amount of work 10 per cent. will be gained on the area of the grates, with a corresponding saving of weight in the boilers when air-heaters are used. This saving in weight will more than compensate for the extra weight of the air-heaters as estimated above, should the boilers weigh more than 0·59 ton per square foot of grate, which is the general allowance in cylindrical boilers. In tubulous boilers, the weight of which is always less than this, and which is as low as 0·32 ton, an increase of weight is unavoidable when air-heaters have to be adopted.

If, further, the saving in the weight of fuel be taken into account, and the total weight of the coal be added to that of the boiler, with and without air heaters, it will be found that a saving in weight will result from heating the air.

From a pecuniary point of view a saving of 10 per cent. in the fuel will, within a short time, cover the prime cost of the installation.

§ 6. FIRING.

46. *Work of the Stokers.*—The main object of the stokers, and by no means an easy one to obtain, is to fire so as to maintain a uniform and constant thickness of coal on the grate, which should bear a direct proportion to the consumption per square foot. This uniform thickness is extremely difficult to obtain, especially on long grates, and excessive inrushes of air will take place wherever the coal happens to be a little thinner. The fireman's motto should be "little and often." The relation between the thickness of the fire and the consumption per square foot of grate will regulate itself automatically, provided that the charges are put on in an equal and regular manner. The furnaces should be charged very quickly, as the currents of cold air have a most pernicious effect, both on the calorific efficiency of the furnace and the life of the boiler.

When stoking is properly conducted, all the furnaces should receive as nearly as possible equal charges at equal intervals

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of time; this is particularly necessary for the water-tube boilers of the Belleville, D'Allest, and Niclausse type, and the charges should be small and at frequent intervals. Thus, on the trials of the *Friant*, with Niclausse boilers burning 25 lbs. per square foot of grate, three or four spadefuls, weighing about 30 lbs.,

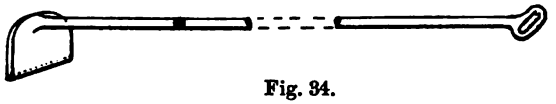

Fig. 34.

were put on the fire at about two-minute intervals, each grate having an area of 39·15 sq. ft. The better the stokers the thinner the uniform thickness of fire they are able to maintain, and the more uniform the thickness the better the distribution of air in the furnace. The mean thickness should be from 4 to 6 ins., and increased as the intensity of the

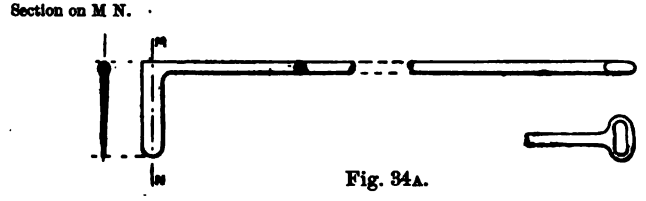

Fig. 34A.

forced draught increases, but very good stokers will not much exceed 4 ins. even at a high rate of stoking.

If the coal becomes caked at any part of the furnace, combustion at that point ceases almost entirely, the total combustion decreases, and repeated charging only tends to further block the grate. The shovel is the stoker's principal

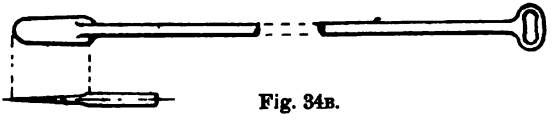

Fig. 34B.

tool, and the ability with which an experienced stoker will handle it is remarkable, but is the result of a long apprenticeship. The other tools, such as rake, lance, etc., used in cleaning the grates, need not here be dealt with.

47. *Cleaning of the Grates.—Self-cleaning Fire-bars.*—The

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D'ALLEST TUBE CLEANER.

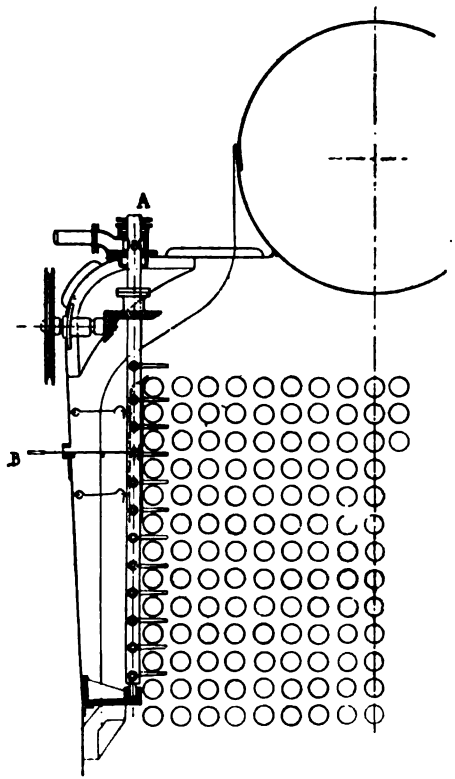
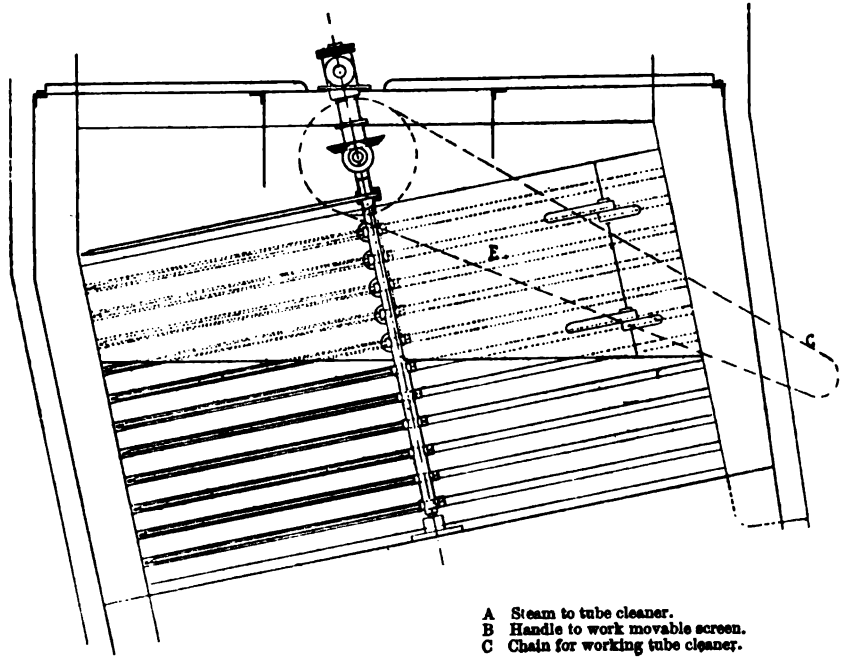


Fig. 35.



A Steam to tube cleaner.
B Handle to work movable screen.
C Chain for working tube cleaner.

Fig. 35A.

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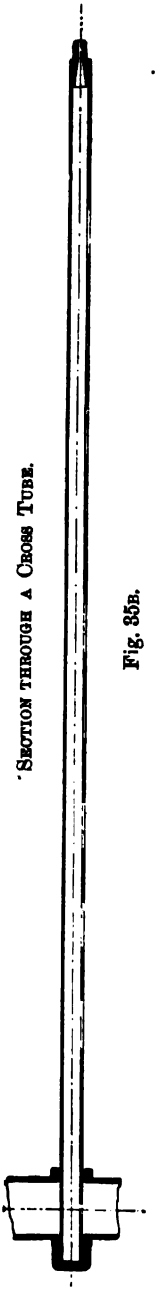
coal, when burnt, leaves behind it an incombustible residue, composed mainly of silicate of alumina and other alkaline silicates. The clinker collects on the bars, obstructing the air passages, and needs removing at regular intervals, varying according to the percentage of incombustible matter and the coal being burnt. Removing the clinker is a difficult operation and is generally performed about once in every eight hours. In trials for coal consumption, great care must be exercised in this operation.

Self-cleaning grates with movable bars have been used in America to get over this difficulty, and apparently with good results. M. Niclausse is at this moment experimenting on a system of injecting steam into the ashpit (Section 7) with a view of preventing the formation of clinker on the bars.

48. *Tube Cleaning.* — Soot on the heating surface of the tubes is not less to be avoided than clinker on the grate. Twenty-four hours after starting, and then every twelve hours, the tubes ought to be cleaned. On cylindrical boilers a brush is passed down the tubes or a jet of steam sent through them; this operation is an easy, though a very disagreeable one on account of the heat, especially in the case of direct-tube boilers. On tubulous boilers steam cleaning is almost the only feasible plan, although it necessitates making up the fresh water expended.

The Belleville and Niclausse boilers are comparatively easy to clean on account of the arrangement of their tubes.

M. D'Allest has invented a tube cleaner for his boiler which carries out the work very quickly. It is shown in Figs. 35, 35A, 35B. It consists of a single vertical tube with a large number



SECTION THROUGH A CROSS TUBE.

Fig. 35B.

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of horizontal tubes branching off from it; these small tubes, by being rotated, pass between the boiler tubes somewhat in the form of a comb. A fine jet of steam escapes from the end of each tube, and also from a long, narrow slit down their sides (Fig. 35B), and by this means the cleaning is general and thorough. The D'Allest apparatus, which works well and is not liable to accidents, should be used on all horizontal water-tube boilers. Unhappily the form of the tubes precludes its use on boilers of the Du Temple type.

On the Du Temple boilers, with curved tubes, the brush can only reach a certain portion of the tubes, and therefore, to completely clean them, recourse must be had to steam cleaning. The largest portion of the soot is carried towards the chimney, but a certain portion of it always falls on the lower drums, from whence its removal is a matter of some difficulty. This difficulty of cleaning the tubes is one of the most serious inconveniences inherent in this class of boiler. If the boilers are only under steam for a short length of time, then the tubes may be cleaned by a powerful current of air. This is effected by utilising the steam left in the boiler, after the fires have been drawn, to work the fans, closing up the stokehold and then quickly opening and shutting the fire and ashpan doors. This method, employed with great success by M. Chevalier, of Normand & Co., Havre, is a very strong proof of the solidity and endurance of the boilers of the Du Temple type. A similar operation would mean destruction to many other types of boiler. This question is further dealt with in Section 88.

49. *Priming.*—Priming takes place by the juxtaposition of the bubbles of steam, which become connected on the surface of the water instead of bursting, and thus form a sort of emulsion, half liquid, half gaseous, filling the steam space and passing over to the cylinders. The old return-tube boilers, especially those working at a low pressure, were particularly liable to prime, although very steady in other ways. Priming is due to two causes—a very abundant production of steam, and to the viscosity of the water. A simple calculation shows that a cylindrical boiler, with three furnaces, evaporating five tons of

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water per hour, produces about 13¼ million bubbles of steam of 0·078 in. diameter under a pressure of 170 lbs. per square inch. Under these conditions the bubbles can disengage themselves from the water fairly easily, but at a pressure of 57 lbs. the number of steam-bubbles produced was nearly treble the amount, and the slightest incident gave rise to tumultuous ebullition. The sudden opening of the stop-valves or the throttle-valve may often give rise to priming by occasioning a fall of pressure in the boiler, and a consequent greatly increased production of steam.

The best means of prevention are to give as large a surface as possible for the disengagement of the steam, and to raise the pressure, thereby reducing the volume of the steam.

Great care must be taken that nothing of a soapy nature finds its way into the feed water. The combination of fatty acids, arising from the lubrication of the cylinders, with the alkaline substances introduced into the feed water, were for a long time a source of constant danger. Boilers whose interior surface had been coated with oil as a means of preservation needed carefully boiling out before being put into service. The introduction of mineral oils for lubrication of the cylinders and valves was a great step in advance. It enabled rates of evaporation to be realised on torpedo-boats, which, under other circumstances, would have emptied the boiler through the steam-pipe by excessive priming.

The absence of soapy matters is not alone sufficient, and certain sources of water-supply for this very reason must be avoided.

The good effects arising from the use of mineral oil led to the adoption of this substance as a preventive for priming, and sufficient quantity was introduced into the boiler to give a layer of about a sixteenth of an inch over the whole of the surface of the water, in order, so to speak, to filter the bubbles of steam and cause them to break and leave their water behind. Be this as it may, mineral oil in a boiler does not float for long, but sinks and forms a brown deposit which is a very bad transmitter of heat, and dangerous to the heating surfaces, as has been noticed in Section 76.

When, in spite of all precautions, priming does take place, it

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is immediately noticeable by the disappearance of the water in the gauge-glasses and the shocks or hammering that follow in the cylinder. To avoid a breakdown in the engines, the speed is reduced and all the drain-cocks on the cylinders and piping opened. At the same time the fires are eased down by shutting the ashpan doors, and even sometimes by opening the smoke-box doors; but this last remedy is not to be recommended. Once priming has commenced it has a very pertinacious way of continuing, in spite of any reduction in the rate of working; but by suddenly shutting the main stop-valve the pressure is increased, which breaks up the bubbles of steam in the steam space and restores the water level.

A sudden disappearance of the water level ought never to give rise to anything in the form of a panic. After opening the feed checks to their full, one can easily afford to wait patiently for a few minutes. On a return-tube cylindrical boiler the furnace crowns may remain uncovered for nearly ten minutes if there is any rolling, or say five minutes if the vessel is steady, without fear of overheating. In a direct-tube boiler, where the crown of the fire-box is more exposed to the direct action of the flame, a critical temperature will be more quickly reached.

Given that there were sufficient water in the boiler before priming commenced, enough water will be left, even though it be in the form of an emulsion, to prevent the plates overheating. The engineer can safely reassure his stokers, and avoid, say for ten or fifteen minutes, drawing the fires, which should only be resorted to as a last extremity.

Amongst tubulous boilers, those with limited circulation, and those where the water level is in the tubes, are especially exposed to heavy priming, should, owing to a fall of pressure, the rate of evaporation be suddenly increased; thus it is necessary to start the engines gradually when supplied with steam from Belleville boilers. Tubulous boilers with accelerated circulation are much less liable to priming, especially if the water level is high in the steam-drum.

50. *Accidental Disappearance of the Water Level.—The Effect*

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of Rolling.—If the water level disappears from the gauge-glasses without producing any shocks or knocking in the cylinders, and more particularly if the time of its disappearance is not accurately known, energetic measures may have to be taken, and the fires drawn. It should be borne in mind that the collapsing of the crowns of the combustion-chamber in tubular boilers may lead to very grave consequences for the *personnel*, and with tubulous boilers the overheating of the tubes, though not so serious for the stokers, is very much more disastrous to the boiler itself. The accidents that have occurred on torpedo-boats are very instructive in this direction, and amongst them may be mentioned the collapsing of the crown of a locomotive boiler on board torpedo-boat No. 122, the complete destruction of the inner row of tubes on board the *Coureur*, fitted with the Thornycroft boiler, and a similar accident on board the *Averne*, fitted with the Du Temple boiler. The cause of the accident in each case was found to be shortness of water.

Sometimes it is not the shortness of water that gives rise to accidents, but the fact that the passages containing the hot gases have been lifted above the normal water level of the boiler, due to an alteration in the trim of the vessel. Excessive rolling may give rise to this difficulty, and it is a source of danger to which the engineer must be alive, more especially as some vessels heel considerably when the helm is put hard over; but moderate rolling or pitching which causes the water level to oscillate may, on the contrary, be looked upon as a safeguard.

51. *Various kinds of Accidents.*—The form of accident to which a boiler is more particularly prone, and the means taken to prevent the same, vary with every type of boiler. It is sufficient to state here that, in cylindrical boilers, the furnace tube-plates and tube-joints are the most delicate portions, and the most exposed to serious accidents. Tubulous boilers are, on the whole, stronger, but they need handling with greater care, and the accidents to which they are exposed, though not so dangerous, are very numerous, and sometimes difficult to repair. Thus it is impossible to plug a tube while under steam.

Serious accidents are more likely to occur in the piping than

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in the actual boiler, and their gravity depends very largely upon the presence of mind of the stokers, since it is often impossible, for want of time, to examine the cause and give any orders. With a crew of experienced stokers, such as is usually met with on trial trips, there is every chance that the stop-valves will be shut down, should a rupture take place in the piping, before the stokehold becomes filled with steam.

If the leakage occurs in the boiler itself it may drive the gases back through the fire doors or ashpan doors, and soon render the stokehold unbearable. To overcome this, when running under the closed stokehold system, the air-pressure must be increased by increasing the speed of the fans, and at the same time the safety-valve should be eased. Fire doors should be so arranged that, should a rise of pressure take place in the furnace, they cannot open of their own accord, and further, the ashpan door should always be made to close automatically.

In case of leakages, either in the boiler or in the piping, the only other general recommendations that may be advanced here are—to ease the safety-valves, open the main stop-valves, and, if possible, not to abandon the stokehold with heavy fires on and an insufficient feed.

52. *Special Conditions of Firing on Trial Trips, and Length of Trials.*—On official trials, where the rate of combustion is as high as possible, and where the coal has to be burnt to the best advantage, the employment of very skilled stokers is necessary, and necessitates on the part of the engineers in charge a practical training, which can only be acquired by years of service. Objections have often been raised to these excessive full-power trials, but they are nevertheless necessary to prove what strain the machinery will stand, and in order to establish a comparison under similar conditions. The consumption trials, on the other hand, serve the purpose of determining the probable consumption when in service. In all consumption trials, whether at full speed or otherwise, the coal is measured and put into sacks, and the quantity put on the fire can thus be very accurately determined. The duration of the trial, which should cease at a time

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when the quantity of coal on the grate is precisely similar to that at the commencement of the trial, is somewhat difficult to determine with exactness; in fact it is impossible, even for a very experienced judge, to determine exactly the quantity of coal on a grate. On a grate with a thick fire no visible reduction in the thickness is perceptible in six to eight minutes, but, nevertheless, in a trial of four hours the amount consumed in this time must amount to three or four per cent. of the total consumption.

M. Joessel has made use of the following method for determining the length of a consumption trial; the principle involved is sound enough, but its practical application is not without difficulty. To start with, all the furnaces are charged, which naturally gives rise to a fall in pressure, combustion is allowed to continue, and the pressure rises and remains stationary until such time as it again begins to fall, and this is taken as the commencement of the trial. Similar operations are carried out at the close of the trial. The position of the dampers not having been altered, it is taken for granted that the moment when the pressure begins to fall in the two cases indicates a similar condition of grate. This hypothesis, however, does not take any account of blocking of the grates.

In one of the colleges in America another method has been advocated, which is sufficient for purposes of comparison. The fires are drawn at the beginning of the trial, and the grate is recharged with a given weight of coal and wood; the trial is then continued, and at the close the fires are again drawn and the contents of the furnace are weighed. The complexity of this method is sufficient to rule it out of court for all practical purposes. The most exact method of conducting accurate consumption trials seems to be to adopt a regular and methodical system of stoking prior to the commencement of the trial, charging the grates regularly at stated intervals, so that the fires may have thoroughly settled down prior to the commencement of the trial. The trial is stopped at an interval of time after the last charge, which corresponds exactly with the interval between the commencement of the trial and the charge immediately preceding it. By plotting the consumption in the

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form of a curve while the trial is in progress, it is easy to eliminate any irregularities which may have occurred at the beginning or the end, and to ensure that the rate of combustion corresponds closely to the mean combustion throughout the trial.

This system of methodical stoking at stated intervals, which was proposed thirty years ago by Rear-Admiral Labrousse and then abandoned, seems to be coming more and more into favour again, not only for consumption trials, but also when it is desired to obtain the best results from the coal burnt.

53. *Experiments on Mechanical Stoking.*—Numerous attempts have been made to introduce mechanical stoking, with the object of getting a more regular combustion than is possible even with the most methodical hand stoking, and to obviate the heavy work entailed upon the stokers. The most ingenious system amongst the many tried in the French Navy was that where the grate was composed of a number of endless chains known as the "Galle" system. Chains were placed close together and kept in movement, the coal was distributed evenly over the bars at the furnace-door end, and arrived at the bridge completely burnt. The cleaning of the fires was also done automatically.

After repeated trials at sea all the various systems of mechanical stoking have had to be abandoned and the human stoker with his shovel and rake again installed.

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CHAPTER V.

LIQUID FUEL FOR MARINE BOILERS.

54. *Different Descriptions of Petroleum used for Heating Purposes.*—The continuous and automatic stoking of boilers, the difficulties of which in the case of coal have been fully realised after repeated attempts to employ mechanical stokers is reduced to a comparatively simple matter when petroleum is employed.

Petroleum, recently introduced as a fuel, is obtained from two great centres of production, viz., near Pittsburg in America and the district of Baku on the Black Sea. Baku petroleum, or rather the residue after distillation which constitutes the heaviest and least volatile part, is an ideal fuel for marine boilers.

Baku petroleum, when submitted to distillation, gives off, in the first place, some extremely inflammable gases which are allowed to escape; after these, are given off the lighting oils, or kerosene, which form about 80 per cent. of its total weight; then the lubricating oils, less inflammable, but still very fluid, and which are used for machine lubrication; lastly, the viscous residue of heavy oil, called Mazout or Astatki, which has never been used except as a fuel, and was for years allowed to go to waste. The proportion of Mazout amounts to about 17 per cent. of the total oil.

Mazout does not give off any vapour below 248° F., and will not flash under 302° F.; it may be exposed with impunity to the explosion of a Hotchkiss shell; its storage and handling present therefore very little risk; it does not contain less than 11·7 per cent. of hydrogen, which gives it a high calorific value, in common with all mineral oils.

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Pennsylvania petroleum contains no Mazout; when employed for heating purposes, which is frequently done in America, whether in land boilers or in locomotives, it is invariably kerosene which is burned.

The navy refuses to adopt such a dangerous combustible, leaving alone any question of cost.

55. *Heating by the Combustion of Liquid Petroleum.—Trays and Wicks.*—In the early attempts to burn petroleum in its simple liquid state, which took place some twenty years ago, the oil was allowed to flow along the bars of the fire-grate, which were hollowed out in the form of shallow trays or channels.

M. Sainte-Claire-Deville tried this method in his laboratory and also on board the steam yacht *Puebla*. M. Zédé also tried this method twenty years ago in the arsenal at Brest.

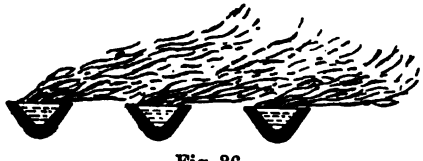

Fig. 36.

The contact with the air was found to be totally insufficient; the combustion slow and irregular, with excessive production of smoke.

M. Nobel of St. Petersburg obtained a better result from the trays by placing them one under the other in such a manner that they were all heated except the bottom one, and he was thus able to burn the petroleum in the most perfect state of all, viz., the gaseous state.

This arrangement has only been applied to some metallurgical operations, and has not been further adopted.

In order to ensure the oil having a sufficient surface in contact with the air to complete combustion, wicks were provided; but inasmuch as the advantages gained in a lamp with a double current of air could not be realised, the results obtained were very imperfect.

The apparatus of this description which has been most tried in the French Navy is that of M. Ferrari of Genoa. It is composed of longitudinal trays containing wicks separated by

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screens so arranged as to distribute the air; a tube pierced with holes placed beneath each wick distributes the oil throughout its whole length.

Two series of trials were made at Toulon with Ferrari wicks, on the *Amalia* and on torpedo-boat No. 139.

On the *Amalia* the object in view was very moderate firing; two trays only being fitted in each furnace in place of the fire-bars; the power developed with a compound engine has not exceeded 100 horse-power per furnace.

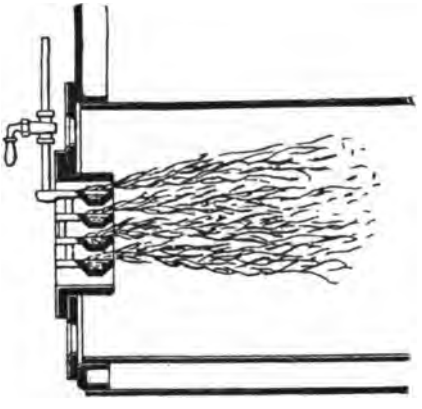

Fig. 37.

Even under these conditions the combustion was incomplete and flaming occurred.

The consumption was, however, satisfactory when compared with coal; on a trial in dock, it was 2·12 lbs. of Mazout per horse-power per hour, and at sea, only 1·79 lbs., although the coal consumption on this ship is 3·022 lbs.

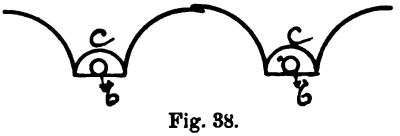

Fig. 38.

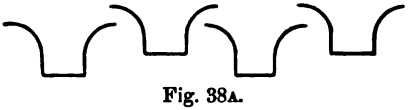

Fig. 38A.

The trials on torpedo-boat No. 139 were made with the object of obtaining very rapid firing with forced draught. The trials were made with nine trays, Fig. 38, and with fifteen trays arranged at different heights, Fig. 38A; various arrangements were tried both with the screens full of holes and with different descriptions of wicks. The result, however, was most discouraging, and did not at any time equal the power obtained with coal.

56. *Firing with Petroleum Vapour.*—However suitable the

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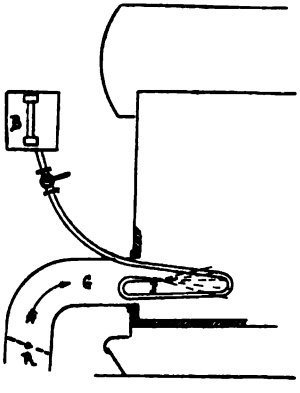
liquid state may be for distribution, it is evident that it does not adapt itself readily to the process of combustion.

In order to ensure the complete mixture with the air required for the chemical combination, it is necessary to go a step further, and bring the fuel to a gaseous state. This arrangement has been tried, but only in a small number of apparatus constructed to burn the volatile oils of the kerosene grade.

In the Leblond and Caville boiler the kerosene is forced by a pump into a reservoir from which it flows under pressure through a bent tube, as shown in Fig. 39; the oil becomes vaporised in the bend of the pipe which passes through the flame, and escapes through a flattened jet. Two jets are sufficient to replace the ordinary grate in a furnace 3 feet 3 inches wide; the combustion must take place, whether with natural or forced draught, under the system known as "the closed ashpit system."



B. Petroleum reservoir.
F. Burner.
G. Air inlet.
R. Damper.

Fig. 39.

On a Du Temple boiler tried at Cherbourg, Messrs. Leblond and Caville evaporated 11·5 lbs. of water with natural draught and 9·46 lbs. with forced draught.

In the Symon-House burner (Fig. 40) the oil is vaporised in a cylindrical reservoir R, exposed to the action of the flame, and in which it follows a circuitous course.

The inflammable gas escapes through a jet, the opening of which is regulated by a needle attached to the regulator supplying air to the burner.

The burner is started by heating up the reservoir R with a lamp. An igniter, or more properly a re-igniter, filled with fire-clay, has recently been fitted over the jet, in the centre of the reservoir.

The Symon-House boiler, supplying steam to a compound

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Fig. 40.

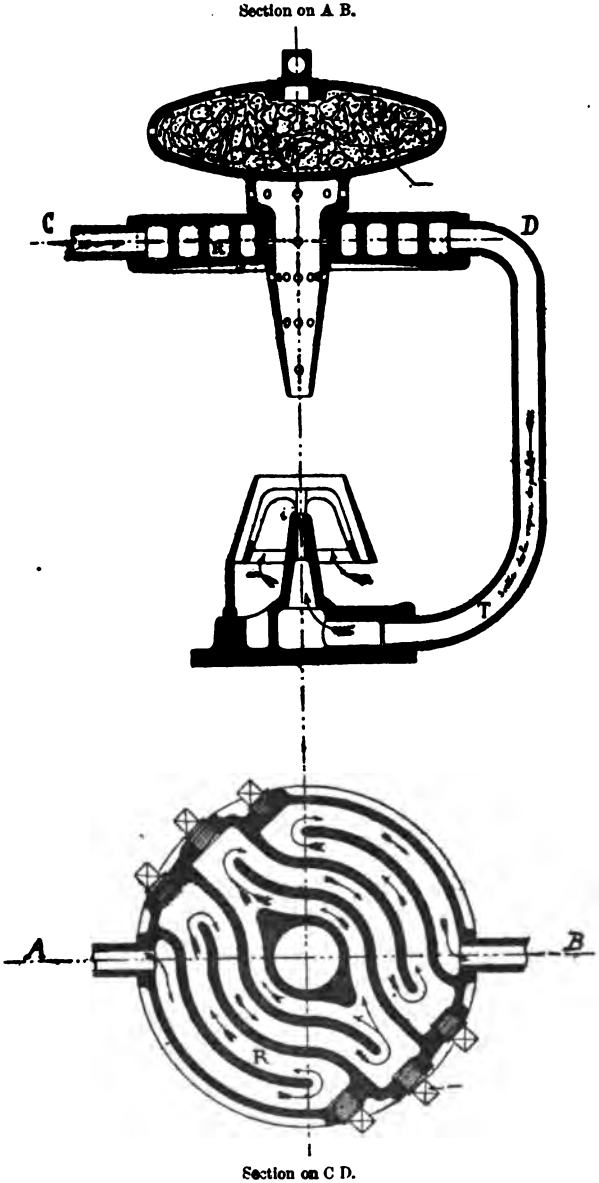

Fig. 40A.

SYMON-HOUSE BURNER.

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engine of 19·7 horse-power, burns 2·23 lbs. of petroleum per horse-power—a result which does not appear a very economical one.

In the Escher-Wyss motor, which uses petroleum as a vaporisable liquid, the boiler itself provides the jet of combustible vapour.

Instead of vaporising the petroleum it is possible to direct it at a high pressure through orifices small enough to reduce the oil to a very fine spray closely mixed with air. This arrangement, which requires an oil of great fluidity, can only be used for small powers, and is mainly used for lighting purposes in lamps, and in starting apparatus on boilers fitted with sprayers or atomisers.

57. *Descriptions of Different Atomisers.*—The means almost universally adopted for burning mazout consist in directing a strong jet into the furnace through orifices large enough to allow it to escape freely and regularly, notwithstanding its viscosity, especially if care is taken to surround the oil-pipe with a steam-jacket. In order to reduce the jet to a fine spray, it is usual to combine a strong jet of steam or compressed air with it, either at an angle, or more often concentrically. A steam or air-jet, at a pressure of 85 lbs. per square inch, is used for spraying a jet of oil under a pressure of 43 lbs. The resulting spray mixes itself thoroughly with the air through which it passes, and, when the supplies of oil and steam or air are regulated in the proper proportion, gives a clear flame, without smoke. The oil-jets are supplied by a force-pump drawing from a small reservoir, or by a pump which maintains the oil-level in the tank supplying the jets as nearly constant as possible.

The nozzles or atomisers, for the combustion of petroleum in this form, are of many different designs. As a rule, the orifices are circular or annular, the jet of oil being placed in the centre of the jet of steam or air. This arrangement is more easily controlled, works with greater regularity, is less costly than other designs, and renders pulverisation more complete. Occasionally a supplementary concentric nose-

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piece is added, for the supply of additional air for combustion, which, however, is not under pressure.

Sometimes very narrow rectangular slits are used instead of annular nozzles, when the two escaping jets strike one another at a considerable angle. The slit for the oil requires very careful attention and adjustment in order to avoid partial choking of the burner while at work.

The regulation of the two jets and the varying of the power

KAUFFMAN BURNER.

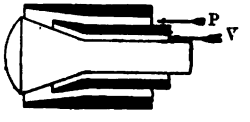
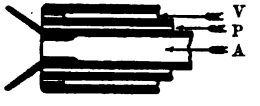


Fig. 41.

ANDERSON BURNER.



V. Steam. P. Petroleum. A. Air.

Fig. 42.

of the burner to the intensity of firing required is a somewhat delicate operation.

Suitable stop-valves are provided for varying the pressure of air at the nose-piece.

With the petroleum jet it is sometimes preferable to keep the

URQUHART BURNER.

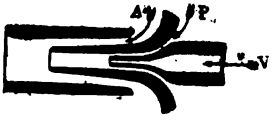


Fig. 43.

CUNIBERTI BURNER.

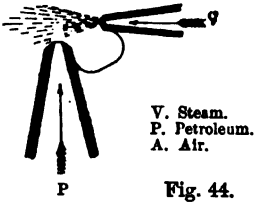


Fig. 44.

pressure constant and to vary the section of the oil-jet by means of a needle. This method is greatly exposed to irregularities of working, inasmuch as mazout flows very badly from an annular slit, and the vibration and want of centralisation of the needle are always to be feared.

It is a much more satisfactory method to construct each atomiser for a given rate of combustion and to vary the number of atomisers according to the rate of firing.

Figs. 41, 42, and 43, show the arrangement of the nozzles in

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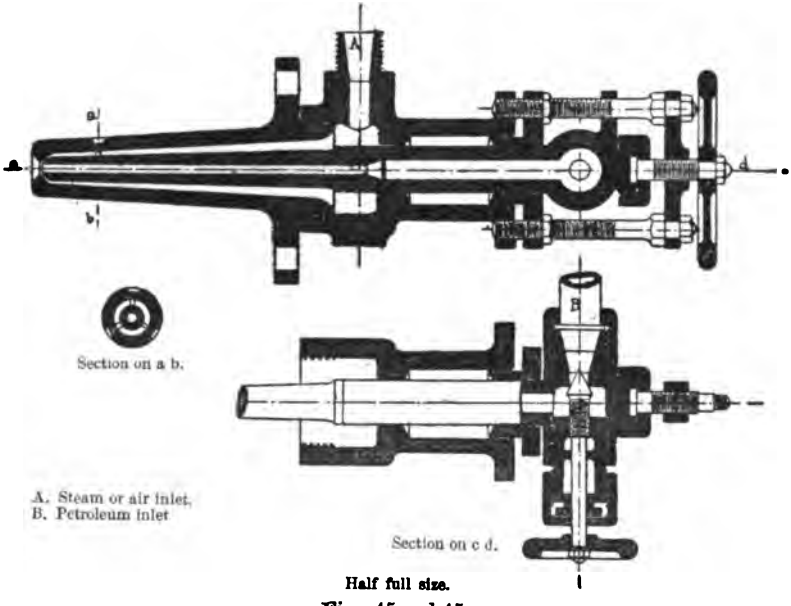
some of the best known American and Russian atomisers. The oil orifice is annular, and a conical screen is sometimes added, in order to produce a further crossing of the jets, thereby ensuring more complete pulverization.

GUYOT BURNER (TORPEDO-BOAT NO. 22).



Half full size.

Figs. 45 and 45A.

The apparatus generally used in the French navy is the Guyot burner, which has been tried on board the *Buffle* and torpedo-boat No. 22; Fig. 45 shows this arrangement. The steam-jet is regulated by the movement of the central spindle, which also forms the oil-supply. Although it is easier to regulate the steam in this manner, great care is required in order that the spindle regulating the steam supply should remain perfectly central. It is also important that the spindles should not be too long, and that they never project beyond the steam-jet, as shown in Fig. 46.

Fig. 46.

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58. *Arrangement of Petroleum Furnaces, Screens, and Brickwork.*—The jet of pulverized petroleum forms a long column of flame; the impact upon a cold surface, such as a boiler plate at a temperature of 300° to 400° F., immediately checks its combustion, and the petroleum deposited upon the plate does not become re-ignited. For this reason special precautions must be taken to ensure complete combustion.

If there is sufficient depth in the furnaces the jet is directed upon a firebrick wall, which becomes sufficiently heated up to re-ignite the petroleum spray when it comes in contact with it. Mr. Urquhart adopts this arrangement on the locomotives of the Graziani - Taretzin Railway, as shown in Fig. 47.

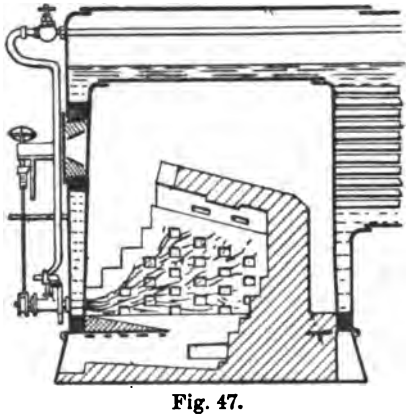

Fig. 47.

The two sides and the top of the masonry screen or baffle which receives the jet are composed of firebrick, pierced with openings, through which the gases of combustion escape; air being admitted from below. A similar arrangement was adopted on a torpedo-boat boiler at Cherbourg in September, 1893, for petroleum burning. The burners were directed transversely across the furnace, and air was admitted from below (Fig. 48).

If the furnace is sufficiently long, it is preferable to leave the flame unobstructed, but sufficient bricks should be fitted under the jet or burner so that should the pulverization be imperfect any petroleum dropping on the red-hot masonry will be ignited. Fig. 49 shows a return-tube boiler fired by petroleum, fitted on torpedo-boat No. 22. The burners in the small ante-furnace are so arranged that the air enters at right angles to the direction of the jet. With this arrangement of the air striking the jets obliquely, the quantity of steam used decreases rapidly as the draught increases. On torpedo-boat

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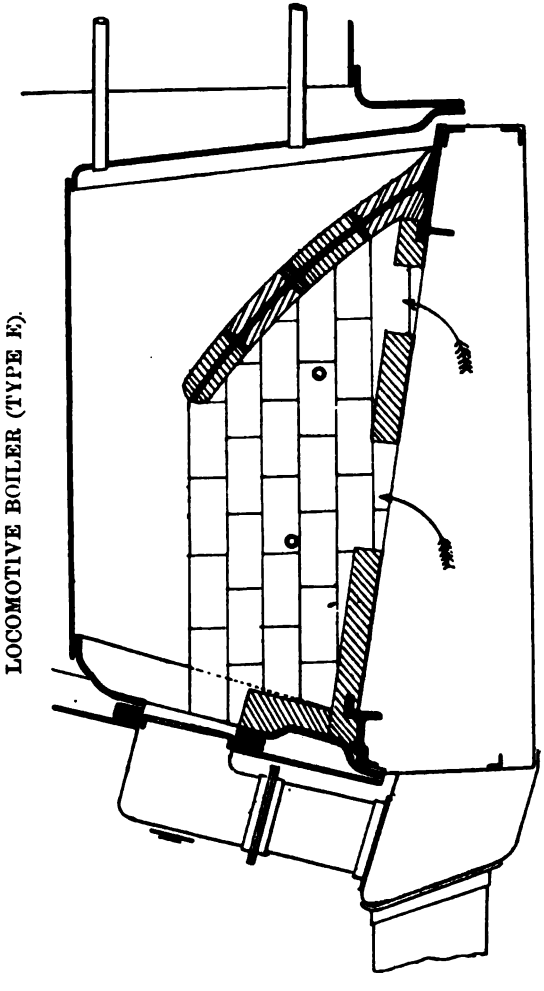
No. 22, 11·06 to 10·08 lbs. of water were evaporated per pound of petroleum with an air-pressure of from $\frac{3}{4}$ in. to $1\frac{1}{8}$ in., and only 9·45 to 8·50 lbs. with an air-pressure of $3\frac{3}{4}$ in. to $4\frac{3}{8}$ in.



LOCOMOTIVE BOILER (TYPE E).

Fig. 48.

On a Godard boiler, with the jets parallel to the axis of the furnace and the air-inlet through the ash-pan, only 8·25 lbs. of water were evaporated per pound of petroleum under an air-

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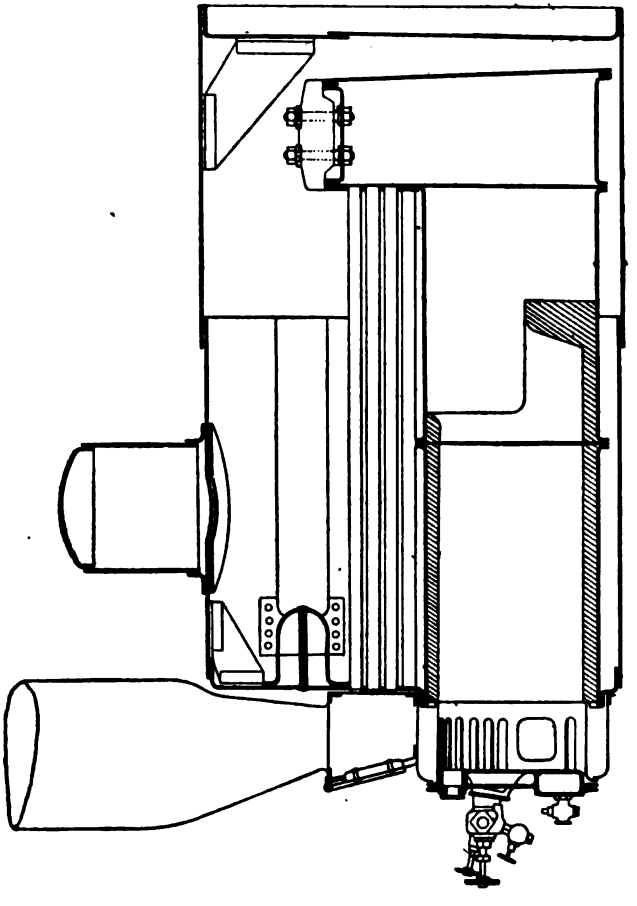
pressure of $3\frac{1}{8}$ in. to $3\frac{1}{2}$ in. Air-inlets parallel to the direction of the flame are the most advantageous way of ensuring good combustion; thus at Cherbourg in 1890, as much as 13·25 lbs. of water were evaporated per pound of petroleum on a return-tube boiler.



BOILER OF TORPEDO-BOAT No. 22.

Fig. 49.

Fig. 50 shows the latest arrangement adopted by M. Guyot, who conducts all the petroleum tests at Cherbourg. The five atomisers are placed in an ante-furnace composed of masonry, the air entering mainly from below. The boiler is of the return flame Du Temple type, as used by M. Guyot. The

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evaporative efficiency decreases as the air-pressure increases, but not in greater proportion than in the case of coal. It fell from 12·5 lbs. of water per pound of petroleum at 0·31 in. air-pressure to 11·3 lbs. at 1·77 in.

59. *Power required to Pulverize Petroleum and Selection of the most suitable agent for the same.*—It is of great importance that the pulverization of petroleum should be carried out as economically as possible.

As a rule, the pulverizing agent is steam, taken direct from the main boilers, and the quantity used varies extremely. In the early trials made in France in 1887, 1·2 lbs. of steam were used per pound of petroleum pulverized. Later, on the *Buffle*, 0·75 to 1 lb. were required, and on the torpedo-boat No. 22, 1·2 lbs. (Figs. 50, 50A, 50B, and 50C). Lastly, on the Godard boiler, 0·46 to 0·12 lb. were used, and 0·53 to 0·75 lb. on a locomotive type boiler tried in 1893.

In trials made by M. Guyot in 1895 on his boiler, he did not exceed 0·63 lb., and got as low as 0·25 lb. of steam per pound of petroleum pulverized. In Italy, similar results from 0·5 to 0·25 lb. have been obtained, and on a Schichau torpedo-boat, as low as 0·102 lb. is said to have been reached. It may safely be stated that it does not require more than half a pound of steam per pound of petroleum vaporised, which is an insignificant amount for land boilers with an unlimited supply of fresh water. On board a ship, however, the fresh water will have to be made up by the distillers or evaporators; this doubles or even more than doubles the present output of the evaporators, which, even at their present rate of working, are often unsatisfactory.

Compressed air, however, may be substituted for steam and has some theoretical advantages, because a given weight of steam can compress up to its own pressure a weight of air superior to itself and the force necessary to pulverize a given quantity of petroleum depends more upon the energy of the jet than upon its volume. It remains to determine whether the resistance of the air-compressor does not more than balance this gain. The early trials made in France,

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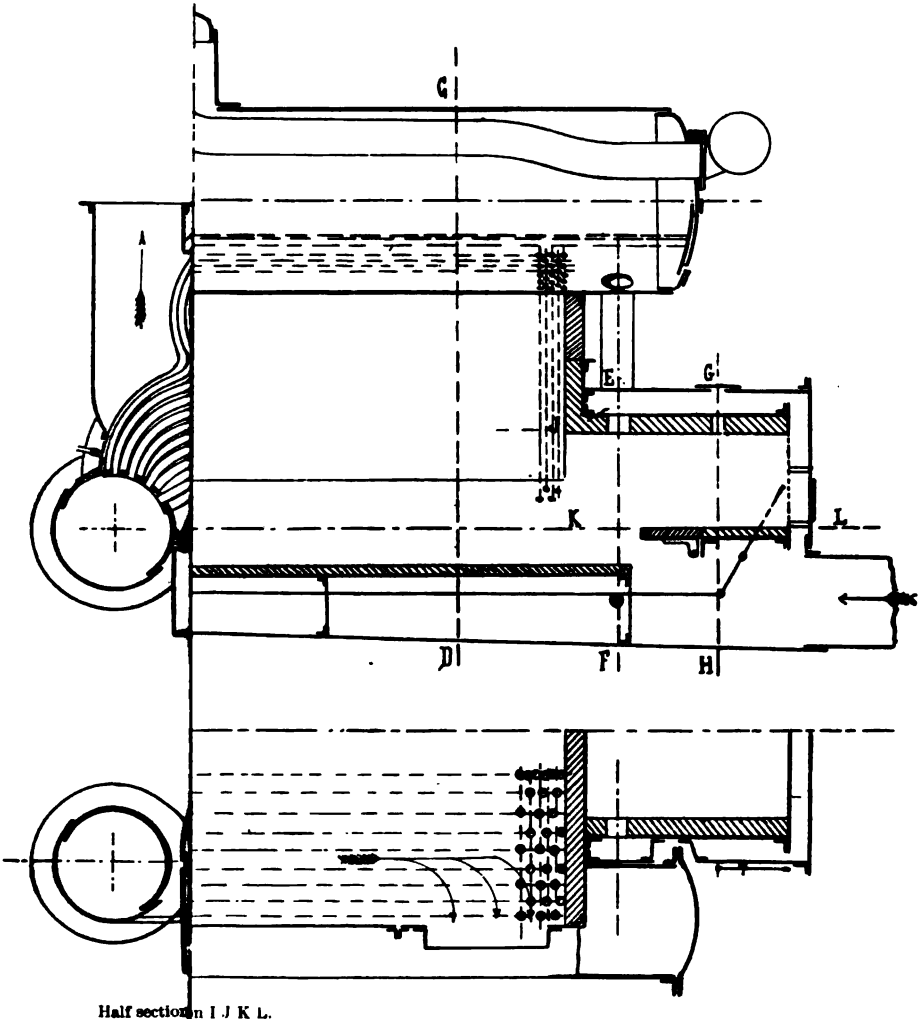
Half transverse section A B.



Half section on I J K L.

a. Air inlet to a

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which date from 1887, were unfavourably reported upon by a commission, which, however, appears to have decided to report unfavourably prior even to undertaking the trials. The general opinion now is, that the consumption of steam when using an economical air-compressor is about half what it would be if the steam were used direct to pulverize the oil. On board ship, the use of an air-compressor gets over the difficulty of the loss of fresh water, and, therefore, the quantity of steam used is only one-fourth of what it would be when pulverizing with steam direct.

The difficulties of lighting up are about equal in both cases. In each case arrangements must be made for the supply of steam or compressed air until the pressure is raised in the main boiler. Recourse must, therefore, be had to some special arrangement for lighting up, whether it be by a special form of burner or by a hand air-pump.

The use of air obviates the risk of projections of oil, and even extinction of the light, which may occur should priming take place or any water come over with the steam when used as a pulverizing agent.

60. *Water Evaporated per Pound of Petroleum.*—The combustion of a pound of mazout develops 20,000 thermal units, whereas a pound of coal only develops 16,400 thermal units. Under similar conditions liquid fuel is, therefore, 1·22 times better than coal. The conditions surrounding the combustion of liquid fuel in the form of a jet, are much more favourable to a complete chemical combination, even when a reduction can be made in the excess of air, which, in a coal-fired grate, carries off 10 per cent. of the total heat produced.

Lastly, the supply of liquid fuel can be easily and constantly regulated; there is no charging of the furnaces, and no cleaning or damping down the fires, which often necessitates a considerable loss and expenditure in coal.

It cannot be denied that mazout has many advantages over coal from an economical point of view, and these can only be appreciated in actual work. In the remarks following, the total quantity of steam generated per pound of fuel is given

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without taking into consideration the steam used in pulverizing the oil. A correction can easily be made for this on the basis of the figures given above. M. D'Allest, who was the first, or one of the first, in France to try liquid fuel, obtained in 1887 an evaporation of 11·33 lbs. per pound of mazout under a high rate of forcing, producing 16 lbs. of steam per square foot of heating surface. Several trials were carried out in the navy before arriving at equally good results, but in 1890, on torpedo-boat No. 22, 11·36 and even 13·25 lbs. of water were evaporated. On the Godard boiler, which was transformed to burn liquid fuel, only 9·6 lbs. was obtained, that is to say, about the same as coal if account is taken of the amount of steam used for pulverization. M. Guyot evaporated in his boiler in 1895 12·5, 12, and 11·3 lbs. in a closed stokehold under an air-pressure of 0·31, 0·67, 1·8 in. respectively.

Thus, an evaporation of 12 lbs. of water seems to be as easily realisable with mazout as 9 lbs. with coal, which gives mazout a superiority of 1·33 over coal, being 1·22 for the difference in calorific value and 0·11 for more perfect combustion. Colonel Nabor Soliani of the Italian navy, who was one of the pioneers in the introduction of liquid fuel, found from trials made on a torpedo-boat that the superiority above mentioned of 1·33 could be considerably increased. The consumption on the torpedo-boat with coal firing amounted to 2·13 lbs. per indicated horse-power, while with liquid fuel it was only 1·25 lbs.

61. *The Advantages of Liquid Firing and its Future.*—The advantages of petroleum are much greater than merely one of a superiority of 30 per cent. in evaporative power, deduction being made for the steam employed in pulverizing the oil, since the work of the trimmers and stokers is not merely simplified but entirely suppressed, and, therefore, the expense and trouble attendant upon the *personnel* is reduced to a minimum.

Over and above the facility of manipulation and the economy in weight, there are other very pertinent advantages. Forced draught with a closed stokehold is rendered much easier by the suppression of the stokers and even of the stokehold

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itself in the ordinary acceptance of the term. The regulation of the fires and atomisers can be carried on through a bulkhead, and no opening and shutting of the fire-doors are necessary. The great regularity with which the fires can be worked obviates one of the principal causes of fatigue to boilers, as it renders unnecessary the opening of the furnace-doors when firing. This enables a higher rate of combustion to be obtained without danger while lengthening the life of the boiler. The fires are always clean and in good condition, which materially increases the average working power of a boiler, because with coal-fired boilers the power necessarily drops as the fires get dirty, and falls still lower while they are being cleaned. When the atomisers are properly regulated and combustion is complete there is no smoke. Lastly, liquid fuel is very much more easily transhipped and stowed than coal. The greatest obstacle to the further introduction of mazout is its price. Mazout in France is about double the price of coal, without taking any account of the duty payable on the same. There are, it is true, many things that tend to compensate for its use, such as the reduction in expediture on *personnel* which may amount to from 50 to 60 per cent. of the difference, and further, the gain in weight and space, meaning freight-earning power or armaments, should account for the remaining 40 or 50 per cent. But the actual price of mazout, largely due to the early difficulties in its employment, will rise very quickly directly the demand increases. The above remarks apply to the price of mazout in Europe alone, as it has only been tapped up till now at Baku, and is scarcely used outside the Mediterranean. Its use on board ocean-going steamers is not practicable on account of the difficulty of refilling the tanks. Further, the present output of mazout is only a very small fraction of the total fuel required should it come into extended use, and for this reason, not to mention others, its employment must remain limited for the present. The first really important application of mazout was made on board the torpedo-boats.

If, in the future, new petroleum districts were discovered in different parts of the world, and if M. Mendelejeff's hypothesis on the formation of petroleum is correct, the question will assume

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a totally different aspect, and liquid fuel will entirely displace coal even if we have to use oils which afford even less security in their manipulation than does mazout.

62. *Mixed Firing and its Advantages.*—On board large boats, where it is not a question of completely replacing coal by liquid fuel, some of its more prominent advantages may be gained by fitting to the present furnaces, say a couple of small petroleum burners and spraying over the incandescent coal jets of petroleum. The main advantage of this mixed firing lies in being able to obtain at will a large increase in the power of the boilers, as the combustion of the petroleum does not in any way prejudicially affect that of the coal, and it also lies in being able to still maintain the power of the boilers even when the grates are covered with clinker, leaving the cleaning of the furnaces to a more convenient time.

The quantity of water evaporated is after all only of secondary importance in mixed firing, but to arrive at the efficiency of the dual firing this quantity must be known.

63. *Comparative Efficiency of the Two Fuels under Mixed Firing.*—In the first place, it must be noted that the introduction of jets of petroleum alters the condition and efficiency of combustion by more completely mixing the gases and burning any excess of air. It is, therefore, not correct to consider the evaporative power of coal as identical when passing from ordinary to mixed firing. Admitting this as a principle and supposing the quantity of water evaporated by the coal to be constant, the extra evaporation due to the better mixing of the gases is credited to the petroleum.

For a given boiler, if

a be the quantity of water evaporated per pound of coal under ordinary conditions, and

b the quantity per pound under mixed firing,

p the quantity of petroleum burnt while consuming c lbs. of coal, and

x the quantity of water evaporated per pound of coal under mixed firing;

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then, assuming a to be constant, the steam produced by the mixture of fuel, $p + c$, is equal to

$$p\,x + c\,a;$$

therefore, for 1 lb. of the mixture we have

$$\frac{p\,x + c\,a}{p + c} = b$$

which gives

$$x = \frac{b\,(p + c) - c\,a}{p} = b + \frac{b - a}{\frac{p}{c}}$$

If we call R the ratio of the evaporative efficiency of petroleum to that of coal, we have

$$\mathrm{R} = \frac{x}{a} = \frac{b}{a} + \frac{\frac{b}{a} - 1}{\frac{p}{c}}$$

There have only been a few evaporative trials made with coal alone and with mixed firing on the same boiler, and very few results have been published. On the *Furieux*, after a trial with coal alone, when 18·8 lbs. of coal were burnt per square foot of grate per hour, two trials were made of mixed fuel with different proportions of petroleum, when 21·3 and 21·7 lbs. of mixed fuel were burnt. The results of these trials, which were carried out under similar conditions, are as follows :—

$\frac{p}{c}$	a	x	$\frac{x}{a}$
	lbs.	lbs.	
0·00	9·05	—	—
0·45	9·05	11·34	1·25
0·64	9·05	14·12	1·56

In the last trial, the efficiency for petroleum when burnt

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in conjunction with coal is higher than when burnt alone. This ought to be the case under favourable conditions with mixed firing, but it is not always so. On a trial at Cherbourg, with mixed firing on a Godard boiler, transformed for mixed combustion, with a high rate of forced draught and petroleum jets not properly arranged in the furnace, the efficiency b was inferior to that of a for coal alone. Although actual evaporative trials are scarce, combined engine and boiler trials, giving the consumption per horse-power with mixed firing or with coal alone are, on the other hand, plentiful. These trials may serve as bases of comparison, always assuming that the calorific value of the coal remains constant.

If C be the consumption of coal per indicated horse-power when burnt alone, and c and p the consumption of coal and petroleum per horse-power when mixed, the quantity of petroleum p, which will produce one horse-power per hour, will be $C - c$, and as the calorific efficiency is inversely proportional to the amount of coal necessary to do a given amount of work, we have

$$R = \frac{C - c}{p}$$

This formula only holds if the two trials of coal alone and mixed firing were carried out at not too high a rate of forced draught. Generally, a high rate of forced draught is not favourable to the use of petroleum, and the ratio of p to c should be decreased as the rate of combustion increases if the efficiency R is to be greater than 1, that is to say, if mixed combustion is to show a gain over the combustion of coal alone. There must exist for each rate of forcing a ratio between p and c which corresponds to the minimum value of the total consumption per horse-power $p + c$, and another ratio corresponding to the maximum horse-power that can be developed. The number of complete trials that have been made is not sufficient to determine definitely the laws relating to mixed firing; the following Table, which is a *résumé* of the trials made on a locomotive boiler on torpedo-boat No. 109, may be consulted with interest.

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——	1st series.			2nd series.			3rd series.
Air-pressure— inches of water . . .	0·6	0·51	0·47	1·0	1·0	1·14	1·97
Coal alone— lbs. per H.P. hour C .	2·99	2·99	2·99	3·02	3·02	3·02	3·37
Coal— lbs. per H.P. hour c .	2·19	2·04	1·30	1·59	1·61	1·46	2·72
Petroleum— lbs. per H.P. hour p .	0·85	0·87	1·10	0·90	1·06	1·46	0·97
Total— lbs. per H.P. hour $p + c$	3·04	2·91	2·40	2·49	2·67	2·92	3·69
$R = \frac{C - c}{p}$	0·94	1·09	1·53	1·58	1·33	1·07	0·67

The above Table shows that good results may be hoped for at natural draught, or at very moderate rates of forcing, when burning slightly less petroleum than coal. Thus at natural draught, when burning 16·4 lbs. of coal per square foot of grate per hour, with a combustion of 12·3 lbs. of mazout with an efficiency of 1·5, the same power would be developed as when burning 34·8 lbs. of coal. Under these conditions, mixed firing may replace forced draught, over which it has many advantages.

The trials made on the *Papin*, *Surcouf*, and *Forbin*, although satisfactory, did not give the favourable results expected of them. On the *Milan*, with Belleville boilers, mixed firing showed no appreciable advantage, but it must be admitted that the proportion of petroleum to coal was very low. On the *Surcouf*, on the contrary, where, on a trial with coal alone, the extraordinary consumption of 4·13 lbs. per horse-power hour was reached when developing 1400 H.P., a consumption of only 2·4 lbs. of mixed fuel was required when developing slightly under 1200 H.P.

Liquid fuel trials are now being extensively carried out, and this is particularly the case in the Italian navy.

64. *Other Applications of Petroleum.*—In dealing with the application of petroleum, we have not yet spoken of the case in which the boiler is dispensed with, and the petroleum is

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burnt in the cylinder of the engine. Though petroleum motors have been largely used on shore, they have not yet been used on board ship, even for auxiliary engines. Since some years, numerous applications on board small boats, yachts, etc., have been made of a motor where petroleum is used both as a vaporising agent and as the fluid vaporised. The engine and boiler are contained in the same air-tight casing. The petroleum vapour, on leaving the cylinder, where it has done useful work on the pistons, exhausts into a casing surrounding the crank and connecting rod, where it acts as an automatic and continuous lubricant. These motors, designed by Mr. Escher-Wyss of Zürich, are worthy of a careful study with a view to ascertaining their economy, due account being taken of the latent heat and the specific gravity of the mineral oil as compared with that of water. The latent heat of evaporation of the hydro-carbons is about eight to ten times less than that of water.

Under this heading we may mention the attempts to use petroleum in the form of briquettes, with the object of utilising the greater calorific value of petroleum while burning it on grates similar to those employed for coal. Various trials made at Toulon on the briquettes made by M. Maëstracci and those of the Compagnie des Combustibles Intensifs, have not realised the results expected of them. It would seem that the principal advantage of petroleum is inherent in its liquid state, and it is not in the direction of solidified petroleum that further researches should be made.

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CHAPTER VI.

§ 1. PRODUCTION OF HEAT.

65. *Total Efficiency of a Boiler.—Sub-division into Furnace Efficiency and Utilization of Heat.*—The efficiency of a boiler is determined from the results of trials with a fuel of known calorific value. If, for example, we take the case of the old rectangular boiler which evaporated 8·5 lbs. of water per lb. of coal, at a pressure of 28·4 lbs., we find that the thermal units expended were 9,680, assuming that the feed-water was at a temperature of 50° Fahr. and the dryness fraction of the steam is 1. The calorific value of Anzin coal being equal to 16,560 thermal units, the efficiency of the boiler is thus 58·4 per cent. With the modern boiler evaporating 9·6 lbs. of water at a pressure of 114 lbs., the efficiency under the same conditions would be 67 per cent. Taking into account the fact that steam produced by a cylindrical boiler contains about 4 per cent. of water, the actual efficiency of tubulous boilers may be stated as being about 65 per cent. For any boiler the efficiency can be determined by an evaporative test similar to the tests made on coals purchased for the French Navy.

The efficiency of a boiler is the product of two distinct factors, the first expressing the degree of completeness of combustion in the furnace and smoke-box, the second being the quantity of heat transmitted to the water.

The combustion in a boiler, neglecting the coal lost with the ashes, can never be as complete as in the pure oxygen of Berthelot and Vieille's bomb calorimeter, because the flame is always extinguished too soon by being prematurely cooled down. It is generally admitted that a boiler can never utilise

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more than 14,000 thermal units instead of 16,560 thermal units, which gives a maximum efficiency of 85 per cent. Upon this point there is only the analysis of the flue gases to rely upon. It is likely that in certain tubulous boilers with very small combustion chambers the foregoing figure is never reached.

The proportion of heat actually utilised can be estimated when the temperature of the furnace and that of the gases at the base of the funnel is known. If, for example, the furnace temperature is 2,912°, which is a maximum value, and the temperature of the outgoing gases is 572°, which is a minimum value when the temperature of water and steam is 392°; the loss of heat is then $\frac{572}{2912}$, or 18·75 per cent., neglecting the latent heat of the steam contained in the gases.

The funnel temperature is often as high as 662°, 752°, or even higher. The loss of heat in the funnel may be increased in two directions. Firstly, by a high temperature in the funnel, which may be due to an inefficient boiler or incomplete combustion, and secondly, by a lowering of the furnace temperature due to an excess of air in the furnace.

To the loss by the hot gases passing out of the funnel must be added that due to radiation and conduction, which is difficult to estimate, but which may be taken as about 5 per cent. on a well-lagged tubular boiler; finally there is the heat carried away by the cinders falling into the ash-pit.

The total heat transmitted to the water may be estimated at 75 per cent.

Combining the two efficiencies of 85 per cent. and 75 per cent. gives very nearly for the total efficiency the value 65 per cent., which was given above as that of the tubular boiler employed on the coal-tests.

In tubulous boilers the efficiency of the furnace varies considerably according to the different types. On the other hand, the heat utilised has sometimes been very small, and it is no uncommon thing for the base of the funnel to become red hot. Great progress has been made in each of these two directions, but sufficient data are not yet to hand to enable a universal rule to be established. The following figures show the utiliza-

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tion of heat in a Mosher boiler which was experimented upon in America:—

Heat utilized in evaporating the water	76·0
Heat lost in the funnel	13·0
Heat lost in radiation	9·1
Heat lost in the cinders and by the evaporation of the water in the ashpan	1·9
Total heat of combustion	100·0

Radiation is greater and more difficult to overcome in tubulous than in tubular boilers.

66. *Quantity of Air required for the Complete Combustion of Coal.—Loss of Heat due to Excess of Air.*—The quantity of air theoretically necessary for the complete combustion of 1 lb. of coal is easily calculated when the chemical composition of the coal is known. Let us assume that this coal contains 85 per cent. of pure carbon and 5 per cent. of hydrogen, the remaining parts being made up of other constituents, including oxygen. Atmospheric air containing 0·0186 lb. of oxygen per cubic foot, 142·6 cubic feet of air will be required for the complete combustion of 1 lb. of carbon, and 420·7 cubic feet for the combustion of 1 lb. of hydrogen. The coal we are dealing with would then require 121·2 cubic feet of air to consume the carbon and 21·035 cubic feet for the hydrogen, making in all 142·2 cubic feet of air per pound of coal burnt.

The actual burning of the coal in the grates, which will be described later, requires the presence of a considerably larger quantity of air than is given by the preceding considerations, though the precise amount required in excess is unknown. Some experiments made in 1873 at Indret by M. Joessel on the old type of boiler with natural draught gave him the following results:

Coal burnt per square foot of grate per hour . . . . . lbs.	15·2	18·2	21·1	25·8
Velocity of air through ashpit door . . . . . feet per sec.	14·6	14·6	13·3	13
Volume of air per pound of coal . . . . . cub. ft.	368·5	307·6	240·3	193·8

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Another series of trials, made in 1877 by the Author on board the *Résolue* with a cylindrical tubular boiler, gave some results which had a wider range because they were made both with natural and forced draught. The first trial is with natural draught, the others are with forced draught produced by blowing jets of air into the funnel. The velocity of the air in the furnaces is deduced from observations made in different parts of the only door leading into the stokehold.

Coal per square foot of grate . . . . lbs.	19·7	28·7	32·6	36·7	40·4
Inches of water in the smoke-box . . in.	0·32	0·51	0·58	0·63	0·69
The speed of air in the ashpan . feet per sec.	10·5	12·7	13·2	14·2	14·7
Volume of air per pound of coal . . . cub. ft.	363·6	301·1	281·9	262·7	248·3

According to these figures the ratio of the quantity of air actually supplied to the amount theoretically necessary is, in round numbers, 2·5 with natural draught and for a combustion of 20·5 lbs., 2 with forced draught and a combustion of 30·75 lbs., and 1·75 for a combustion of 41 lbs.

Much higher rates of combustion have been obtained since these experiments, but no observations with regard to the actual consumption of air have been made.

It has long been known that an excess of air in the furnaces is necessary to ensure complete combustion. Considerable advantage has been found in admitting air above the grates. These currents of air, which are admitted partly through the fire-doors and partly through the furnace bridges, slightly diminish the draught above the grate, and, in consequence, the passage of air through the coal and the amount of coal burnt. But by ensuring more complete combustion they appreciably increase the power of the boiler. The velocity of admission to the furnace for air which has not to pass up through the fire easily reaches 40 to 50 feet with natural draught, so that only very small openings above the grate are necessary.

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In cylindrical return-tube boilers one-third of the total quantity of air may be admitted above the grate with advantage, an amount which is equal to one-half of the volume of air passing through the grates.

The presence of air in excess of that necessary to support complete combustion and which passes up the funnel carries with it a large amount of heat. The specific heat of the gases at constant pressure being about 0·23, each cubic foot of air admitted in excess per lb. of coal burnt and passing out at 572° carries with it

$$1{\cdot}3 \times (572° - 32°) \times 0{\cdot}23 = 161{\cdot}4 \text{ B. T. U.}$$

or more than 1 per cent. of the total heat produced.

The combustion of 1 lb. of coal by 19·5 lbs. of air produces 20·5 lbs. of gas with a specific heat of 0·23. The temperature of the hot gases is then about 3,000° if the quantity of heat produced is equal to 14,040 B. T. U. The 20·5 lbs. of gas passing out through the funnel at a temperature of 572° carries off 2,650 B. T. U., or 18·8 per cent. of the heat produced, which agrees very closely with the figure given in Section 65.

67. *Combustion of Coal.—Chemical Reactions.—Temperature of the Flame.*—Let us now consider what takes place upon a grate covered by a fire of uniform thickness. The coal burnt per hour and per square foot depends upon the amount of air which passes through the fire and the depth of coal on the grate.

For any given thickness of fire the rate of combustion increases with the draught, and experiment has shown that within the limits of natural draught it is nearly proportional to the volume of air supplied. Combustion would then be complete and the composition of the flue gases would be constant.

For any given quantity of air the rate of combustion increases with the thickness of the fire until the whole of the oxygen in the air is combined with the carbon in the coal.

Passing now to the consideration of forced draught, and assuming that it is proposed to burn a certain quantity of coal per hour, the usual conditions of stoking are as follows.

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The thickness of the fire is in practice fixed within certain well-defined limits, because it cannot exceed the maximum thickness beyond which the grate will become choked and the combustion incomplete, nor can it fall below a certain limit depending on the amount of coal to be burnt. As complete combustion depends on the quantity of air passing through the furnace, directly the thickness of coal on the grate is in excess of the maximum quantity beyond which combustion becomes incomplete, choking of the grate rapidly takes place. A reduction in the supply of air is thus coincident with an excess of the coal supply. No exact measurements have been made of the thickness of fire giving a maximum combustion at various draughts. In practice 6 in. to 8 in. mean thickness is never exceeded in ships when burning from 20 to 40 lbs. With higher rates of forcing a thickness of from 8 to 10 in. may be allowed, but good stokers usually prefer to keep a thin fire for the reasons given above.

Combustion takes place in the following manner. The lower surface of the coal receives the current of air and very active combustion takes place, resulting in the formation of carbonic acid; the temperature reaches at least 3,000° Fahr. The flame is a white red in colour. As the current of gas rises it contains a constantly increasing proportion of carbonic acid, which is decomposed by contact with the incandescent fuel.

$$CO_2 + C = 2\ CO$$

Combustion continues at the expense of the oxygen still contained in the gas, but producing carbon monoxide as soon as the oxygen ceases to be in excess. The temperature corresponding to these reactions is much lower than the preceding one. As the current rises, the air, which is still being gradually deprived of its oxygen, encounters the green or newly-charged coal; here the volatile hydro-carbons are being given off in long thread-like streams of gas and the temperature falls yet lower. On the upper surface of the coal the movement of the flames increases the contact between the remaining oxygen and the combustible gases, carbon monoxide, and the hydro-carbons; at the same time a new influx of air

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through the apertures in the fire-doors causes a great increase in the intensity of combustion.

In order to ensure good combustion a large combustion chamber is needed; this is met with upon cylindrical return-tube boilers, though even here the dense volume of smoke given off when the furnaces are freshly charged, and the deposit of soot in the tubes, show that the combustion is far from perfect. On boilers with the tubes leading direct out of the furnace the conditions are even worse. Upon the earlier Belleville and Niclausse boilers the combustion chamber was reduced to practically nothing, and consequently a large excess of air, such as is furnished by forced draught, was absolutely necessary. Upon recent boilers, with accelerated circulation, the height of the furnaces has been much increased in order to give ample space for the proper mixing of the gases.

68. *Smoke and its Analysis.*—The only indication as to completeness of combustion is given by the smoke. Thick smoke indicates incomplete combustion, and is caused by the too sudden cooling of the gases before the hydro-carbons have been burnt. The analysis of the gases is easily carried out by means of Schloesing and Orsat's apparatus, which gives very reliable results, and from which practical deductions can at once be made. If 1·5 to 2 per cent. of oxygen is found in the flue gases it can at once be stated that the fire is too thick and the rate of combustion is too high, as regards efficiency, for the draught employed. If the proportion of oxygen exceeds 8 per cent. the fire is too thin, the draught too great, or the air-passages above the grate are too big. Finally, if an excess of carbon monoxide and uncombined oxygen be present the boiler itself is at fault, and will never work economically whatever the draught may be.

To sum up, what is aimed at is the highest possible efficiency for a given rate of combustion, efficiency and rate of combustion being independent of one another. To obtain this result two means are available; by regulating (1) the thickness of the fire, and (2) the amount of draught.

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§ 2. TRANSMISSION OF HEAT TO THE WATER AND TO THE STEAM.

69. *Transmission of Heat.—General Principles of Conduction of Heat.*—The transmission of heat from the furnace gases to the water takes place through the metal forming the heating surface in the three following stages:—

(1) From the gases to the heating surface.

(2) Through the thickness of the metal separating the gases from the water.

(3) From the surface of the wall in contact with the water to the water itself.

We have then to examine:—

(1) The temperature of the hot gases, T.

(2) The temperature of the heating surface next the fire, T_1.

(3) The temperature of the heating surface next the steam or water, t_1.

(4) The temperature of the water or saturated steam, t.

We know the law of transmission of heat through metal.

$$Q = C\frac{\theta}{e}. \quad (1)$$

Q being the number of heat-units traversing per second a unit section of one square foot.

C is the coefficient of conductivity of the metal.

θ The difference in temperature $T_1 - t_1$.

e is the thickness of metal in inches.

The following are the values of C for iron, copper, and silver:—

Iron	0·129
Copper.	0·806
Silver	1·096

These coefficients of conductivity are sometimes expressed in terms of the conductivity of silver.

Little is known with regard to the conductivity of the deposits which often cover metallic surfaces, save that, as a general rule, they are extremely bad conductors of heat.

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The transmission of heat between the hot gases and the walls, and between these and the water, is regulated by unknown laws. It is, however, known that it is not effected by conduction, as fluids conduct very badly, but by convection; that is to say, heat is carried away by the particles of fluid which succeed each other in contact with the metal. Continued movement of the fluid is therefore necessary. It is also known that heat passes more readily between the water and the metal than between the hot gases and the metal—3,500 times more readily according to Mr. Milton of Lloyd's. This figure is, however, only partially justified by the difference between the conductivities of water and gases, which are estimated as being 0·00155 in the former, and 0·000045 in the latter case, silver being taken as unity.

It follows, from the great difference between the conductivities of water and the hot gases, that, whatever their true values may be, t_1 differs very much less from t than T_1 does from T, and as T_1 and t_1 differ very little from each other, the temperature of the containing walls of the boilers under normal conditions approaches very nearly to that of the water. Any cause which tends to prevent the transmission of heat to the water, tends also to increase T_1 and t_1.

As the value of θ in equation (1) is unknown, this equation is of little use until Q is known, when it may be used for calculating the value of θ.

The only difference of temperature that can be measured (and even then only approximately) is—

$$\Theta = T - t.$$

Q can only be determined experimentally as a function of Θ.

Mr. Blechynden experimented upon a small boiler having a definite heating surface in contact with the hot gases, of known temperature; he measured T, t, and the amount of water evaporated, from which he obtained the value of Q.

These experiments, made with different surfaces and thicknesses of metal, gave results which showed that the following law held very generally :—

$$Q = K \Theta^2, \tag{2}$$

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K being a constant for the same surface in contact with the flame whatever the value of Θ.

Formula (2) being accepted, it is easy to find the value of K for the whole of the heating surface of a boiler the evaporative power of which is known.

Let us take the case of a boiler in which each pound of coal burnt produces 14,040 B. T. U., distributed amongst 20·5 lbs. of gas at 3,000° F., which pass out at a temperature of 572° F., abstracting 2,650 B. T. U., and let us assume that the temperature of the water and steam is 392° F. Assuming, finally, that the combustion is 20·5 lbs. per square foot of grate, and the ratio of heating surface to grate surface is 40, we can now proceed to determine Q.

If Q be the total quantity of heat transmitted by one square foot of heating surface, the quantity of heat passing through a small surface, ds, is equal to $Q\,ds$; the decrease in temperature, $d\Theta$, of the 20·5 lbs. of gas, taking into account its specific heat, 0·23, will be given by the following equation:—

$$d\Theta = \frac{Q\,ds}{20{\cdot}5 \times 0{\cdot}23} = \frac{Q\,ds}{4{\cdot}715}.$$

Replacing Q by $K\,\Theta^2$ (formula (2)) we obtain

$$d\Theta = \frac{K\,\Theta^2\,ds}{4{\cdot}715}$$

$$\frac{d\Theta}{\Theta^2} = \frac{K}{4{\cdot}715}\,ds.$$

$$(3) \qquad -\frac{1}{\Theta} = \frac{K}{4{\cdot}715}\,S + C,$$

in which S is equal to 1·96 sq. ft. of heating surface, corresponding to a grate surface of 0·049 sq. ft. for 1 lb. of coal burnt per hour.

Assuming the limiting values of Θ, that is, $T - t$, to be 2,520° and 180° we obtain

$$\frac{1}{180} - \frac{1}{2520} = \frac{K \times 1{\cdot}96}{4{\cdot}715}$$

which gives

$$K = 0{\cdot}0125$$

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The quantity of heat which passes per square foot per hour is then

$$Q = 0{\cdot}0125\ \Theta^2 \tag{4}$$

in every part of the boiler.

In the furnace for $\Theta = 2{,}520°$

$$Q = 79{,}380 \text{ B. T. U.}$$

At the entrance of the tubes at the plate, for $\Theta = 900°$

$$Q = 10{,}125 \text{ B. T. U.}$$

At the other extremity of the tubes for $\Theta = 180°$

$$Q = 405 \text{ B. T. U.}$$

From these values of Q, the corresponding values of θ can be calculated by formula (1), care being taken to divide Q by 3600, as the second is taken as the unit of time.

It is found that, in the furnace, for a thickness of metal equal to $\frac{1}{2}$ in., $\theta = 85{\cdot}5°$ F.

It will be seen from the law stated in formulæ (2) or (3) that, with a moderate rate of combustion, and a temperature of the outgoing gases not above 572°, increasing the heating surface beyond forty or fifty times the grate surface has scarcely any effect. This agrees with the results of previous experiments.

Geoffroy, in 1860–64, measured the evaporative efficiency of the different parts of a locomotive boiler composed of segments placed end to end, the tubular portion in particular being composed of four segments. With a moderate fire, corresponding to a combustion of 20·5 lbs. of coal per square foot of grate per hour, the evaporation was 996 lbs. in the first segment through which the gases passed, and only 128 lbs. in the last one; the ratio between these two figures is equal to 8. But supposing that the difference of temperature, Θ, varied regularly from 900° to 180° between the first and last segment, it would have a mean value of 810° in the first segment, and 270° in the last, which gives 9 as the ratio between the two values of Θ^2. This agrees fairly closely with the ratio obtained from the evaporation.

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More complete experiments than those of Geoffroy have been made since then by the Paris, Lyons and Mediterranean Railway Company. The principal results are given in the next section, 69A.

For tubulous boilers it is known that, according to an experiment made by Watt, on the type having free circulation, the row of tubes with which the flame first comes in contact accounts for 60 per cent. of the total evaporation.

69A. *Efficiency of Locomotive Boilers.—M. Henry's Experiments upon the Influence of the Length of the Tubes.*—Boilers of the locomotive type, as described in Chapter IX., have only been used in the navy on vessels such as torpedo-gunboats or similar craft. They have now been abandoned in favour of tubulous boilers.

Upon the railways the locomotive boiler proper, characterised by its long tubes and low grate, continues to give complete satisfaction. The conditions of working differ so much on board ship and upon the railway, that it is not proposed to compare them as regards safety, cost of upkeep, and life of the boiler. The question of their economic working is well worth considering, however, both as regards consumption of coal and utilization of heat. The same factors enter into the efficiency of every type of boiler and the means of improving them are analogous in each case.

Some experiments on the evaporation of locomotive boilers have been made by M. Henry, locomotive superintendent of the Paris-Lyons-Mediterranean Railway. It is interesting to compare his results with those given above for marine boilers.

M. Henry varied in his experiments the length of the tubes and the draught. His boiler, which was similar to M. Geoffroy's trial boiler mentioned in section 69, consisted of a furnace fitted with removable ferrules; tubes of nine different lengths, ranging from 6 ft. 6 in. to 23 ft., could thus be used. The boiler was worked at pressures of 1 in., 1·8 in., and 2·9 in. of water.

The grate surface, A, was about 26·9 sq. ft., its horizontal projection being 24·1 sq. ft. The heating surface of the furnace was 108·9 sq. ft.; the internal heating surface of the tubes varied from 575·6 to 2,015 sq. ft., which gives values of 25 to 79 for the ratio of heating surface to grate surface.

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The other data were :—

Number of tubes	185
External diameter of the tubes . . .	2 ins.
Total area through tubes	3·31 sq. ft.
„ „ ferrules	2·03 sq. ft.

The thickness of the fire in these experiments varied with the draught, in order to obtain the highest possible efficiency; the average thickness appears to have been somewhere about 10 in. When the fires required charging, the fall of temperature in the smokebox caused a thermometer to make an electrical contact and ring a bell in the stokehold.

The draught, produced by a steam jet, was measured by the difference in pressure between the ashpit and smokebox. The steam used by the jet was not measured.

The waste gases were analysed by means of Orsat's apparatus.

The results required for purposes of comparison are summed up in the following Table :—

Length of tubes . .	Ft.	9·84	13·1	16·4	19·7	23·0
Total heating surface .	Sq. ft.	972·2	1260	1548	1835	2122
Ratio $\frac{\text{Heating surface}}{\text{Grate surface}}$	..	36·13	46·82	57·52	68·21	78·91
	In. of Water.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Combustion per square foot of grate at draughts of . . .	1·0	38·21	36·8	33·1	30·3	28·9
	1·8	53·3	50·4	46·3	43·0	41·3
	2·9	70·8	67·0	61·7	57·2	54·8
Water evaporated per pound of coal at draughts of . . .	1·0	16·1	18·5	19·8	20·4	20·9
	1·8	15·5	17·8	19·0	19·6	20·2
	2·9	14·6	16·9	18·1	18·7	19·3
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Total efficiency at draughts of . . .	1·0	66·7	72·8	80·0	84·0	83·0
	1·8	63·1	69·7	77·2	80·2	80·0
	2·9	57·9	65·3	..	73·0	75·2
		Degrees.	Degrees.	Degrees.	Degrees.	Degrees.
Temperature of the gases in the smoke-box at draughts of .	1·0	739	608	518	460	432
	1·8	813	666	561	500	457
	2·9	896	722	603	534	486
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Loss of heat by the funnel at draughts of	1·0	17·4	13·7	11·4	10·2	9·77
	1·8	19·0	14·7	12·3	11·0	10·3
	2·9	21·2	15·9	13·1	11·7	10·9

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The total efficiency of the boiler, as well as the loss in the funnel, is calculated as a percentage of the total heat which would have been produced had combustion been complete. With perfect combustion 14,190 B. T. U. per lb. of fuel would have been developed.

Mariemont briquettes, which are similar in composition to Anzin briquettes, were used as fuel.

The efficiency was remarkably high, as much as 10·2 lbs. of high-pressure steam being obtained per lb. of coal without correcting for temperature.

After the addition of a "Tenbrinck" (see page 208) to the furnace, an evaporation of 10·43 lbs. and an efficiency of 85·5 per cent. was obtained. These results are what must be aimed at in the new tubulous boilers for naval use. Although the efficiency scarcely exceeded the usual figures when short tubes were employed, yet it must be admitted that the great increase shown with the longer tubes is not solely due to the extra heating surface. The reduced losses in the funnel must also be taken into account, due to the fact that the air supplied for combustion did not exceed 176 cubic ft. per lb. of coal.

In the experiments made at different draughts, the amount of air required per pound of coal decreased as a general rule as the draught increased; the mean consumption of air was 161·8, 152·3, and 142·6 cubic ft. for the three different draughts employed. The variation is very much less than it is in the experiments on marine boilers with lower draughts given in section 66; one important reason for this is that the thickness of the fire was much greater at all draughts upon the locomotive than upon the marine boiler.

69B. *Effect of Varying the Arrangement of the Furnace.*— Following upon these experiments made with an ordinary furnace, M. Henry made three other sets. In this latter series, the baffles were placed above the grate and nearly parallel with it, so as to cause the flames to move towards the boiler front, and take a longer course before reaching the tubes, thus forcing the flames to take a somewhat similar course to that adopted on the *Forban*. The two first baffles were brick arches of

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different lengths, placed at a height of about 2 ft. 6 in. above the grate; the third was a "Tenbrinck," placed about 2 ft. above the grate.

These new experiments were made under the same conditions as the first set, different lengths of tube being employed for each experiment. The following results, which are independent of the lengths of the tubes, are the mean of the whole of this latter series of experiments, and show the effect upon the combustion efficiency of thoroughly mixing the gases. The efficiency is based upon the number of thermal units utilized.

——		Ordinary Furnace.	Short Brick Arch.	Long Brick Arch.	Tenbrinck.
	In. of Water.	Per cent.	Per cent.	Per cent.	Per cent.
Proportion of carbon monoxide at draughts of. .	1·0	9·9	7·8	7·0	8·3
	1·8	11·4	7·9	8·1	6·9
	2·9	14·4	8·6	8·5	7·8
Proportion of ashes in ashpit and funnel at draughts of	1·0	1·45	0·74	0·65	0·88
	1·8	2·66	1·48	1·41	1·50
	2·9	4·77	2·85	2·22	3·13
Combustion efficiency at draughts of	1·0	92·0	95·0	95·0	95·0
	1·8	91·0	94·0	94·0	94·0
	2·9	90·0	93·0	94·0	93·0

These results confirm what modern practice has revealed, the necessity for thoroughly mixing the hot gases, especially with very energetic forced draught, in order to burn the carbon monoxide. It should be noticed that the "Tenbrinck," in spite of the lower temperature of its walls, has not been less effective than the brick arch in ensuring complete combustion. A gain of 3 per cent. in combustion efficiency, however, does not by any means represent the increased efficiency of the return-tube boiler as compared with the direct tube type.

M. Henry's experiments led to marked improvements being realised in the combustion in locomotive boilers, with the result that the saving effected has much more than paid the cost of the experiments. For marine boilers these experiments are useful for purposes of comparison, as they show what ought to be obtained with properly arranged and proportioned heating

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surfaces and furnaces capable of ensuring perfect combustion at all draughts. They also form a basis for comparing new types of boilers.

70. *Importance of Cleanliness of Heating Surface.* — The cleanliness of the heating surface has a great effect on the value of that surface for transmitting heat, and therefore the numerical value of K (formula (2), p. 128) varies considerably with the cleanliness of that surface. In the experiments made by Mr. Blechynden upon a vessel with polished surfaces and containing water, K varied from 0·016 to 0·034, according to the thickness of the shell; the mean value of K in English units was 0·024, which corresponds to 0·021 in French units. An ordinary cylindrical boiler, in good condition, with thick furnace plates and thin tubes, will only transmit

$$\frac{0{\cdot}0125}{0{\cdot}024} = 52 \text{ per cent.}$$

of the total quantity of heat which passed through the well-cleaned and even planed surfaces of Mr. Blechynden's experimental cylinder. As soon as the plates are fouled, either by deposits of lime or, especially, of grease, the transmission of heat from the boiler plate to the water is considerably reduced. This is indicated by the rise in temperature of the plate.

Sir John Durston, the Engineer-in-chief to the Admiralty, made, in 1893, some researches on the heating of the walls due to the water not being long enough in immediate contact with them. These researches were undertaken with a view of discovering the cause of several boiler failures which had taken place, and the reasons for which were not apparent. The following figures are some of the results of his experiments.

When heating water in an open vessel, made of iron $\frac{1}{2}$ in. in thickness, the temperature of the fire varying from 2,190° to 2,500°, the temperature of the bottom of the vessel was 280° when the surface was clean; it rose to 310° when 5 per cent. of mineral oil was mixed with the water. When the bottom of the vessel was covered with a coating of grease, $\frac{3}{64}$ inch thick, the temperature increased to 518°.

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When the non-conduction of heat is the result of the formation of bubbles of steam, which are worse conductors even than grease, the result is yet more marked. Sir John Durston measured, by means of fusible alloys, the temperature of the tube-plate of a direct tube or Admiralty boiler, working under forced draught, and burning 92·2 lbs. of coal per square foot of grate per hour, the air pressure being 3 in. The maximum temperature of the hot gases was 3,090°, and that of the water 356°. The temperature of the tube-plate was found to be 1,060° upon the outer surface, and 716° in the centre of the thickness of metal. It will be seen from these figures that the formation of a steam-pocket may easily lead to the burning of the tube-plate.

When the conduction of heat is prevented by a deposit of soot upon the outer surface of the shell, the results become disastrous as regards the transmission of heat to the water, as the obstacle is on the side of the shell where the resistance to conduction is already excessive. As soon as the deposit of soot becomes at all considerable, the marked falling off in power of the boiler shows that the tubes require cleaning. The coating of soot acts as a preservative to the parts of the boiler in contact with the flame; it causes the loss of units of heat, but reduces the risk of overheating.

71. *Transmission of Heat by Convection.*—The efficiency of a heating surface depends upon the rapidity with which the particles of water in contact with it succeed one another.

As regards convection, tubulous boilers appear to be particularly suitable, especially if the tubes are arranged in a zigzag form; but the difficulty of directing the heated gases through each passage between the tubes frequently counteracts this advantage.

The inferiority of the ordinary plain boiler tubes in cylindrical boilers, can be decreased by the use of Guébhard's spirals or retarders, which are flat strips of metal twisted into a spiral form, and placed inside the tubes so as to cause the gases to take a helical course along the tube, or else this inferiority can be diminished by the use of Serve tubes, which are fitted with

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longitudinal and radial webs on the interior of the tube, and so abstract the heat from the centre of the hot gases passing through the tube.

As far as the water is concerned, the circulation alone is relied upon to facilitate the transmission of heat by convection, the adoption of the Serve tube in the D'Allest tubulous boiler being merely to increase the amount of heating surface in contact with the water. The disengagement of the steam bubbles, if they are carried away sufficiently rapidly by the circulation of the water, ensures the renewal of the surfaces in contact. The circulation should be the more rapid in a tubulous boiler, as the quantity of steam produced in a given time bears a much greater proportion to the total volume of water contained than it does in the case of a tubular boiler.

The artificial circulation of the water in cylindrical boilers, and in particular the use of an agitator, would appear to facilitate the production of steam.

72. *Heating Surface and Grate Surface.—Ratio between the two Surfaces.*—The quantity of water evaporated per unit of time and per unit of area from the interior heating surface of a boiler varies from point to point.

Independently of other causes, this great difference proceeds from the radiation of heat from the burning fuel, which, though not great in the case of a flaming coal, is considerable when the furnace is burning a non-flaming fuel such as coke, and is also very noticeable when the fire has been left uncharged for some time. Looked at from this point of view, the heating surface may be divided into two parts, direct heating surface and indirect heating surface, the former being the surface which is directly exposed to the grate. An analogous subdivision is used in cylindrical tubular boilers, the firebox and combustion chamber being the direct, the tubes the indirect heating surface.

Convection exercises a considerable influence on the flames as well as on the water, the furnace-crowns in particular being subject to very intense heating above the furnace-bridges, on account of the rapidity of movement of the hot gases.

The efficiency of the heating surface diminishes rapidly as

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the distance from the fire increases; in fact, when a certain limit is reached, the addition of further heating surface has no influence upon the power of the boiler, as was shown by Geoffroy's experiments mentioned above.

It is generally admitted, that for boilers intended to be worked by natural draught, the heating surface should be about thirty-five times the grate surface, the tubes comprising four-fifths of this area. This proportion is well suited for the combustion of 12 to 22 lbs. of coal per square foot of grate; as much as 33 lbs. of coal can be burnt and 8·5 lbs. of water evaporated per pound of coal if the boiler is free from scale.

Given the heating surface S and the grate surface G, the rate of combustion with a fairly high efficiency is determined by the empirical formula

$$C = K\left(\frac{S}{G}\right)^2$$

Making

$$K = 0{\cdot}0266$$

we get

$$C = 32{\cdot}6 \text{ lbs. per sq. foot of grate}$$

for $\frac{S}{G} = 35$.

With forced draught the proportion of heating surface to grate surface should be between 45 and 50 in order to obtain a combustion of from 41 to 51 lbs. of coal per square foot of grate; nothing is gained by exceeding this proportion, even if the draught be increased.

The extent of heating surface does not indicate the amount of water a boiler is capable of evaporating, nor does the extent of grate area show the amount of coal it can burn. But as the quantity of water evaporated per pound of coal varies very little, the grate area is a considerably better indication of the power of a boiler than is the heating surface, the draught of course being stated.

A boiler has often to satisfy diametrically opposite conditions; thus in order to secure a large extent of heating surface, the number of tubes has to be increased and their diameters

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reduced; whereas, from a practical point of view, it is advisable to keep the diameters as large as possible in order to lessen the danger of obstruction and to facilitate cleaning.

The external diameter of the tubes of tubular boilers is generally about 3 in.; there is an advantage, as far as efficiency is concerned, in decreasing the diameter to 2 in.; even with 2-in. tubes, choking of the tubes with a hard deposit of ashes and soot, which is known as "bird's nesting," need not be feared in a well-constructed boiler if the tube joints are tight.

In the calculation of the grate area there is no difficulty, but in the calculation of the heating surface, certain portions are not usually included; thus the ash-pit surface in cylindrical boilers, and the outside half surface of the tubes, which in some tubulous boilers are arranged as a screen to protect the casings, are omitted. It is absolutely necessary that the same method of calculation be used in every drawing office, in order that the results of trials may be comparable one with another.

73. *Loss by Radiation.—Lagging.*—Boilers are usually covered with a non-conducting substance, in order to diminish the loss of heat by radiation and conduction. This loss has a prejudicial effect in three different ways; it reduces the amount of water evaporated per pound of coal, it is a source of great inconvenience to the stokers, and it may ignite any combustible material which happens to be in the neighbourhood of the uptake.

In tubular boilers the flues are entirely surrounded by water spaces; the exterior surface of the boiler, properly so called, cannot therefore exceed a comparatively low temperature, which is about 400° for the usual working pressures, and which would only be 417° for a pressure of 300 lbs. These favourable conditions preclude all possibility of fire, and enable the lagging of the boiler to be easily arranged for.

For a long time, that is to say as long as the working pressures were below 85 lbs. and the temperatures below 320°, boilers were covered with a coating of felt covered with canvas, having a total thickness of about 1¼ in. and a weight of 0·8 lb. per square foot. A very careful determination of the non-conducting

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power of this lagging was made at Toulon in 1889 by M. Brocard, an engineer in the French Navy.

M. Brocard concluded from his experiments that the loss by radiation amounted to 3,320 B. T. U. per square foot per hour. A boiler with three furnaces like that on the *Jean-Bart* has 656 square feet covered with non-conducting material. This represents a loss of 217,950 B. T. U. per hour, which is equivalent to the combustion of 13 lbs. of coal, or to 1 per cent. of the total heat produced in the furnace with active combustion. This result shows that felt is a sufficiently good non-conductor for all practical purposes, and the loss could be still further reduced by doubling the thickness of lagging, as will be shown later.

Felt, however, has the disadvantage of not being incombustible. It undergoes charring at 390°, a temperature which is often reached in practice, and ignites at 1,200°. Serious accidents have resulted from this, as it takes fire quite as easily on contact with the fire-rakes, ashes and cinders, as from the flame of a lamp or candle. In consequence, the necessity of clothing boilers with some mineral substance, such as asbestos or silicate cotton was recognised. The experiments of M. Brocard were undertaken to determine the relative non-conducting power of these various substances. The following Table embodies the results:—

Non-conducting material employed.	Weight of lagging per sq. ft. in lbs.	Water condensed in lbs.	
		In 10 hours.	Per sq. ft. per hour.
Felt and canvas, $1\frac{3}{16}$ in. thick . . .	0·9	97·0	0·51
Asbestos, 2 in. thick, with a central layer of silicate cotton $\frac{3}{16}$ in. thick	3·3	88·4	0·46
Pure asbestos, 2 in. thick	3·2	86·4	0·45
Silicate cotton, 2 in. thick	3·6	74·7	0·39
Asbestos, $2\frac{3}{8}$ in. thick, with a central layer of silicate cotton $\frac{3}{16}$ in. thick .	3·6	72·7	0·38
Pure asbestos, $2\frac{3}{8}$ in. thick	3·5	72·3	0·38
Felt and canvas, $2\frac{3}{8}$ in. thick . . .	1·7	48·5	0·25

The above Table shows clearly the superiority of felt, weight for weight, as a non-conductor, and more especially is this the case when price is taken into account.

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Mr. Charles Norton very ingeniously applied electricity to measuring the non-conducting power of different substances. A reservoir, containing a rheostat, round which the non-conducting material was placed, was filled with oil. A current was passed through to maintain a constant temperature, and the quantity of watts absorbed by the rheostat gave an exact indication of the value of the various substances as non-conductors.

Upon cylindrical boilers felt was always employed on the sides and for the bottom. The felt lagging upon the bottom of the shell was usually stopped off at some distance from the boiler-front, in order to avoid all risk of contact with the hot ashes, etc., on the stokehold floor. The lower part was usually covered with a thin steel plate about $\frac{1}{16}$ inch thick, so as to prevent contact with the firing tools, which are frequently placed between the boilers after use. The boiler-front was usually covered with felt where possible, care being taken that the covering was stopped at least 16 in. from the flues, and the edge secured by a small iron of Z section; that it was not allowed to come within 10 in. of the floor, nor to be within 6 in. of any manhole through which candles might be introduced into the boiler.

Where felt was not used, a mineral non-conductor, preferably silicate cotton covered with asbestos cloth, was employed. For the boiler-fronts it would have appeared simpler to use mineral non-conducting substances exclusively. When cost is not of primary importance, the use of asbestos cloth to cover the felt has much to recommend it.

74. *Air-casing and Lagging of Smoke-box and Uptake.*—Upon the smoke-box and uptakes, which it is necessary to cover with some non-conducting material, in order to lessen the radiation from the boiler-fronts, two baffles about an inch apart are usually fitted (Fig. 51). The first is of thin iron plate, the second of polished brass from which there is very little radiation. Precautions are taken to prevent the heating of the outer baffle by conduction.

With forced draught and a closed stokehold, these baffles are

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insufficient, since they do not prevent the heating of the air which, unable to escape, collects at the top of the stokehold; silicate cotton can in such cases be used with advantage. On the *Fulminant*, which, however, has not a closed stokehold, the use of silicate cotton has enabled the fans to be placed on a platform directly over the boilers. The wood lagging, which was formerly employed upon the smoke-box doors and upon the uptakes, had to be discontinued on account of the danger of fire.

At one time a somewhat extensive use was made of plastic non-conducting material. It consisted generally of river-mud mixed with one- or two-thousandths of its weight of horse-hair, and was kept in position by a thin plate; sea-mud cannot be used on account of the chlorides contained in it. These plastic coatings are very poor non-conductors; they are nevertheless of value for clothing the base of the funnel, the radiation from which into the stokehold is very inconvenient.

Fig. 51.

The insulation of the funnel itself is always obtained by means of air-spaces. A first casing fixed to the funnel by means of angle-irons forms part of the boiler itself; by carrying it up to the top of the funnel the draught is improved, as the cooling of the air in the funnel is retarded and the air-space can be also used as a ventilator to the stokehold, and even to the cabins. In order to protect the 'tween decks from the radiation from the funnel, it is as well to surround it with a second casing, forming part of the hull. This second casing, which is always useful, becomes an absolute necessity in the case of many of the tubulous boilers at present in use, the funnels of which are liable to become red hot.

Tubulous boilers, as far as prevention of radiation is concerned, are similar to the smoke-boxes of tubular boilers; their casings have even to submit to still more intense heat than do the smoke-boxes of these latter, since some parts of the casing surround, and even form part of, the walls of the furnaces. The non-conducting material employed usually consists, as regards the lower part, of a covering of brickwork, and the higher

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portion is covered with a thin layer of ashes between two thin plates. A wall of brickwork only 2 in. thick has the disadvantage of weighing 16·4 lbs. per square foot, not including fastenings; a layer of cinders of the same thickness weighs 7·2 lbs. per square foot, not including the plates. Certain tubulous boilers lose, by this necessity of clothing, an important fraction of their advantage in weight over cylindrical boilers.

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CHAPTER VII.

75. *Wear due to Chemical Action, producing Deterioration on the Inside of Boilers.*—The preservation of boilers against destructive chemical action, which operates on them by slow degrees during their whole life, follows rules, common to all kinds of boilers, whether cylindrical or tubulous; this is, therefore, a convenient place to notice them, reserving the study of the resistance of the materials to mechanical fatigue until the different types are separately dealt with.

One very general cause of wear and tear, common to all iron structures that are not painted (as, for instance, the inside of boilers), is oxidation due to contact with air or with water. The action is so well known that it is only necessary to mention here that to be operative the presence of air and of water must be simultaneous; neither dry air alone nor pure water exhausted of air has any chemical effect on iron. On the other hand, air, when contained in water, would appear to have a particularly energetic effect when discharged in bubbles against a plate; it would almost seem as if, at the instant when it thus resumes its gaseous form, oxygen had then some of the properties of bodies in a nascent state. Sea-water, however, even when free from air, has a peculiar corrosive action when hot, due to the presence of chloride of magnesium. This chloride, when subjected to heat in water, yields magnesia and hydrochloric acid, the reaction taking place under two different circumstances.

In the first case the acid is formed as soon as the sea-water reaches 212° Fahr., and its density is sufficient; and it is this action which explains the rapid corrosion that takes place at leaky joints and rivet-holes.

In the second case the hydrochloric acid is given off, even in the weakest solution, when the temperature is sufficiently

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high; it is generally admitted that this action commences directly 248° Fahr. is exceeded, that is, at a pressure of 28 lbs. per sq. inch; it follows, therefore, that in high-pressure boilers, heated to between 248° Fahr. and 392° Fahr., the practice so common in the engine-room of making up losses by using sea-water should be absolutely prohibited.

The rapid destruction of the tubes of the Belleville boiler by local pitting has been explained as being due to the use of sea-water. To overcome this difficulty without discarding such an obviously simple method of making up losses as the employment of sea-water, M. Belleville has advocated the use of lime as a reagent; good results have been obtained, so much so that its use has extended to other boilers, notably to those with steel tubes. The use of the lime has been continued, though that of sea-water has been suppressed.

Unlike chloride of magnesium, other alkaline chlorides, when dissolved in sea-water, do not seem capable of giving off hydrochloric acid unless air be present, but they assist in the deterioration of plates at leaky joints. They may also produce the same effect when heated in the presence of hydrate of silica or of sulphate of magnesia, as will be noted further on when studying the action of solid deposits.

76. *The Action of Fatty Acids.—Chemical Reaction of Saline Deposits.*—The most active cause of the destruction of boiler plates for some years past, has been the presence of fatty acids in the feed-water. Surface condensers came into general use at a time when grease and vegetable oils were the only lubricants employed for the interior lubrication of the engines. The glycerine contained in them becomes separated from the fatty acids immediately on their introduction into the steam cylinder, and these latter are carried on into the boilers, where they attack the plates. The principal seats of this corrosion are the surfaces adjoining the feed-water inlet and those near the water-level, where the acids, floating prior to their saponification, are deposited on the shell. This action is all the more dangerous, as a point of corrosion, once having been set up, is more susceptible to subsequent attacks, and deep pitting may result.

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Recourse has been had, as a preventative, to the injection into the boiler of a solution of carbonate of soda; but it is found that the carbonate only neutralises the fatty acids after corrosion has already set in; and, further, that the carbonic acid thus formed has a pernicious effect of its own. Carbonate of soda is therefore no longer used, the only alkaline solution still employed being one of lime.

Deposits found at the bottom of boilers often show distinct traces of the salts of copper, distinguishable by their green colour. Some authors have attached great importance to the presence of copper, on the supposition that it set up galvanic action; but it is well known that this action is almost imperceptible when the proportion of copper to iron is so very small. In fact, the existence of galvanic currents has never been clearly manifest even when brass tubes were used; for iron or steel is hardly affected by the vicinity of brass, owing to the presence of zinc in that alloy.

Deposits formed on inner surfaces act in two distinctly different ways, viz., chemically, as corrosive agents, and physically, as non-conductors, giving rise to overheating. Chemical action is set up both on the surfaces of the shell plates and on the plates forming the flame passages, and probably with the greater energy on the latter. Physical action takes place owing both to mineral and organic deposits, and is confined to surfaces exposed to the direct action of fire.

The chemical action of saline deposits has been recently brought to notice by M. Haas, an Engineer in the French Navy, when examining an Oriolle boiler, of which the tubes had become deeply pitted, and even perforated, under the layer of salts which had accumulated in them. This was explained by the reaction between the chloride of sodium and the hydrate of silica, giving a silicate of soda and hydrochloric acid, and by a second reaction between the sodium chloride and the silicate of magnesia, giving a silicate of soda and a chloride of magnesia, subject in its turn to decomposition by heat.

$$NaCl + SiO_3\,HO = NaO\,SiO_3 + HCl$$

$$NaCl + MgO\,SiO_3 = NaO\,SiO_3 + MgCl$$

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The corrosive effect of saline deposits does not seem to be noticeable at temperatures between 212° and 248° Fahr., at which boilers, fed with sea-water, used formerly to be worked; for these boilers used often to return to port with the water-spaces coated with deposits and yet with their plates intact. Indeed the engineers used to carefully produce a thin deposit on all the plates, furnaces, combustion chambers, &c., to prevent violent ebullition and for the better preservation of the boiler.

The physical action resulting from deposits has always been manifested by the production of blisters in furnace plates and by damage of a similar kind; this action is particularly to be feared on the tube-plates, to which the water has difficulty in obtaining access owing to the large production of bubbles of steam on their inner surfaces.

Mineral oils, deposited on a plate, form a brown varnish which is a particularly poor conductor of heat, as has been pointed out in Section 49, and which, although very thin, may give rise to overheating of the plate. These dangerous deposits are formed when a boiler is emptied without having previously removed the greasy substances floating on the surface of the water by means of the surface blow-off or scum cock; all the surfaces, whether vertical or horizontal, become coated with oil as the level of the water drops. Deposits of this nature explain to a certain extent those collapses of fire-boxes which happen sometimes on the portions most exposed to the fire.

77. *Principal Precautions to be taken to avoid Corrosion.*— The precautions to be taken for the preservation of boiler shells have been dealt with in the preceding section. They may be thus summed up:—

When designing the shells they should have from $\frac{1}{16}$ in. to $\frac{3}{16}$ in. added to their thickness to allow for corrosion.

Plates exposed to the direct action of fire should be single; red-lead joints should on no account be allowed.

The greatest care must be taken that all seams are perfectly tight, and particularly the tube-plate joints, and the use of solid drawn tubes should be insisted on, as it is always in the weld

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that pitting occurs, not to speak of the danger of their splitting in tubulous boilers.

No moist air should be allowed to remain in a boiler when it is not in use. The best way of keeping such air out is to heat the air in the boiler by introducing charcoal warmers through the manholes, and then hermetically closing all openings; or the boiler may be filled up with distilled water that has been deprived of air, with a little lime in it; this last method is frequently employed, especially with tubulous boilers at the present time.

While the boilers are at work, numerous precautions have to be taken, which are partly dependent on the management of the engines. The use of tallow or vegetable oils for the lubrication of the cylinders should be absolutely prohibited, none but mineral oils should be allowed, and even of these only the absolutely necessary minimum should be permitted. The design of slide-valves and of piston-packing has been an object of special study of late years with the view of suppressing if possible all interior lubrication. Even the stuffing-boxes of the main piston-rods and valve-rods are now lubricated with mineral oil.

The condenser tube-joints should be carefully watched, and any loss should be made good with distilled water, to the complete exclusion of sea-water. Sea-cocks on condensers should be condemned, even where they have already been fitted. In its transit from the condenser to the boilers, care should be taken to prevent the feed-water becoming mixed with air. On the other hand, as it is essential that the feed-water should be filtered and cleared of grease, the efficiency of filters and separators should be carefully maintained.

In spite of all precautions, a certain amount of mineral oil is bound to reach the boilers; it is therefore desirable to use the surface blow-off frequently while under steam. Should greasy deposits have occurred, it will be necessary to thoroughly wash the boiler out with soda. The solution of caustic soda used for this purpose in the Messageries Maritimes is fixed at about 5 per cent.; the liquid is brought to boiling point and kept simmering for about an hour, after which the boiler is thoroughly emptied and cleaned out.

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The use of zinc as a preservative has become very general; as has also that of lime in the feed-water; but this latter should be applied with discretion, for it has happened, on some ships, that lime carried over by the steam into the cylinders has caused abnormal wear and tear of the rubbing surfaces.

Finally, when the whole of the boilers are not in use, it is important to watch and see that all valves, whereby steam might find its way into the empty boilers, are tight.

In the matter of boilers, and indeed of engines in general, it is well to always bear in mind that even the smallest precaution has its importance, and that none are insignificant enough to be neglected with impunity.

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PART II.

TUBULAR BOILERS.

CHAPTER VIII.

CYLINDRICAL BOILERS.

§ 1. PRINCIPAL FEATURES.

78. *Single-ended Marine Boilers.*—The different forms of boilers enumerated in Section 13 will now be considered in detail and further examples given.

The so-called "marine" boilers are cylindrical return-tube boilers. They are sometimes called "Scotch" boilers, owing to their having been used, as far back as 1862, by the firm of Randolph Elder on the *Velasquez* and the *Murillo*. They took the place of the old rectangular boilers, similar in principle, which prior to that date had been known as "marine" boilers. These rectangular boilers were not equal to a pressure of more than 17 lbs. per square inch; with cylindrical boilers the pressures began with about 55 lbs., and have now risen to 200 lbs. and over.

Amongst boilers known as cylindrical boilers, a considerable number were greater in height than in breadth, being, as a matter of fact, composed of two half cylinders separated by flat pieces, and were generally known as "elliptical" boilers. Another form was used for a long time in the American Navy, in which the back and front, instead of being flat, were cylindrical in the upper portion forming the steam-chest; neither of these forms are at present in use.

When boilers are placed athwartships, with the stokehold running fore and aft, the lower portions of the back of the

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DRÔME.

CYLINDRICAL MARINE BOILER.

Scale 25 mm. = 1 mètre.

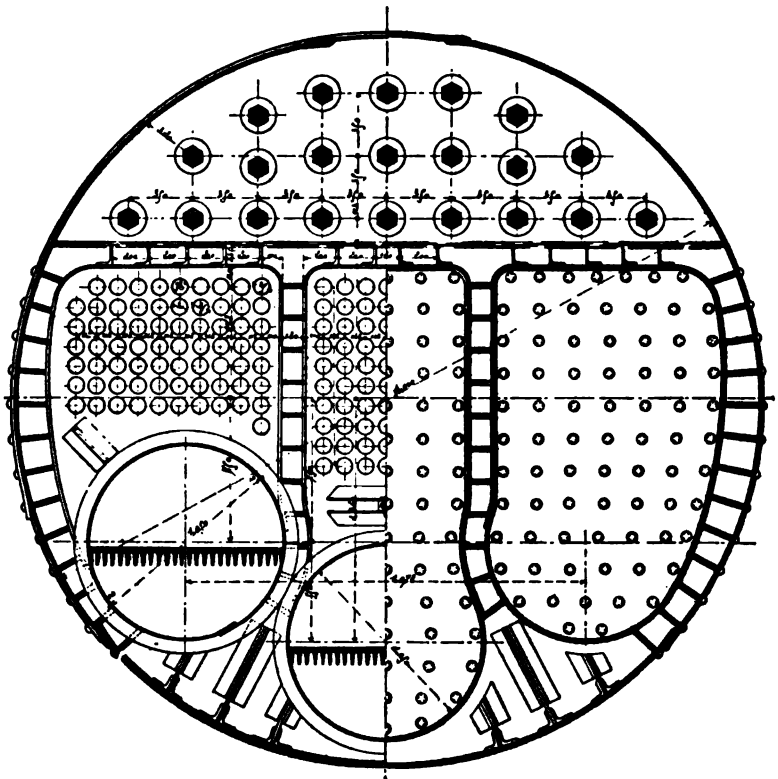

Fig. 52.

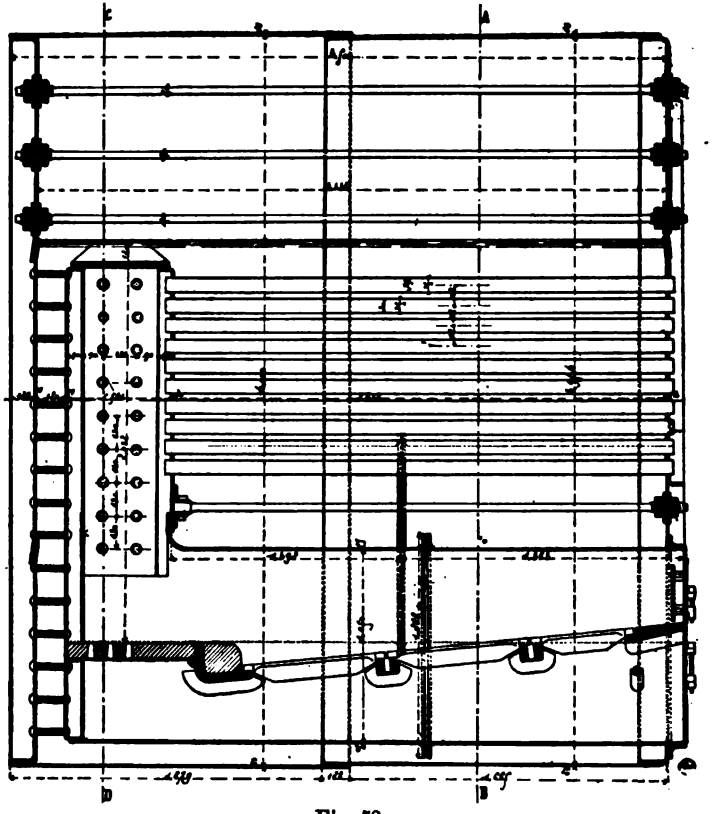

Fig. 52A.

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boilers are often cut away to fit the shape of the hull, thus giving a more roomy stokehold.

The following portions of the boiler are always surrounded by water.

1. The furnaces.
2. The combustion-chamber.
3. The nests of tubes, corresponding to the furnaces, which return the hot gases to the front of the boiler.

The hot gases, on emerging from the tubes, reach the chimney by smoke-boxes exterior to, and independent of, the boiler.

There may be one, two, three, or four furnaces, and when there are more than two they are placed at different heights. They are cylindrical in form and vary in diameter from 2 ft. 6 in. to 3 ft. 6 in. By increasing the number and reducing the diameter of the furnaces the grate area can be increased and a greater quantity of coal consumed; on the other hand, by increasing the diameter of the furnaces and reducing their number, more perfect combustion is obtainable, and the production of steam is proportionally greater. Flaming coals require big furnaces. Generally speaking, large diameters would be preferable had not the strength of the furnaces to be taken into consideration, as the liability to collapse increases more rapidly than the diameter. The combustion-chamber, which receives the gases from the furnace and distributes them amongst the tubes, is the seat of a very active combustion and forms an indispensable prolongation of the furnace. This prolongation is all the more effective, as the reversal of the flame, which takes place in it, agitates the gases and brings the combustible particles into intimate contact with the particles of air. This chamber is generally made equal to half the diameter of the furnace plus 12 in. It would, perhaps, be an advantage to make it even bigger. Combustion is never perfect; the volume of smoke issuing from the funnel, especially while stoking, is a proof of this. Indeed, in practice, the results fall a good deal short of the ideal furnace which would send into the tubes the products of perfect combustion and nothing else, and the re-ignition of the gases at the foot of the funnel, which now occurs, could not then take place.

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WHITE STAR LINER "GERMANIC."

SINGLE- AND DOUBLE-ENDED BOILERS.

Scale $\frac{3}{16}$ in. = 1 foot.

Design No. 1.—Combustion-chamber common to two furnaces at the same end of the boiler.

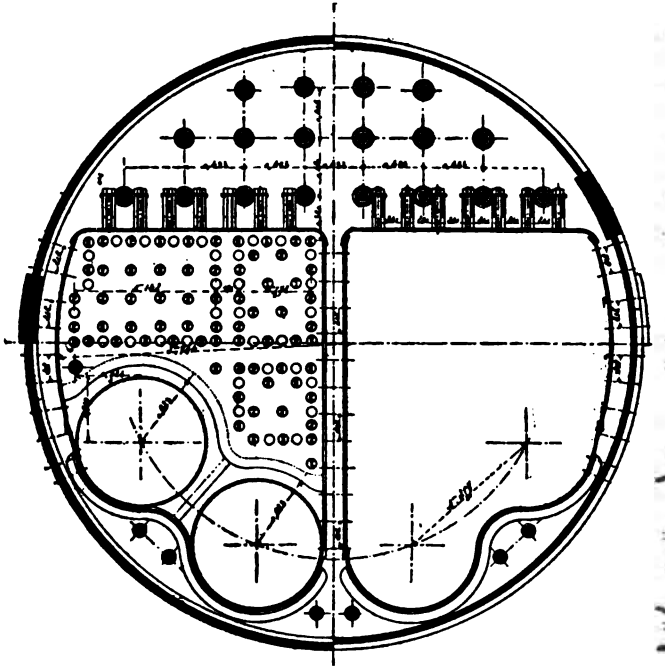

Fig. 53.

Combustion Chamber.

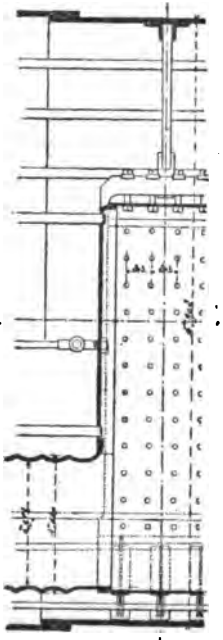

Fig. 53B.

Design No. 2.—Combustion-chamber common to two furnaces at opposite ends of the boiler.

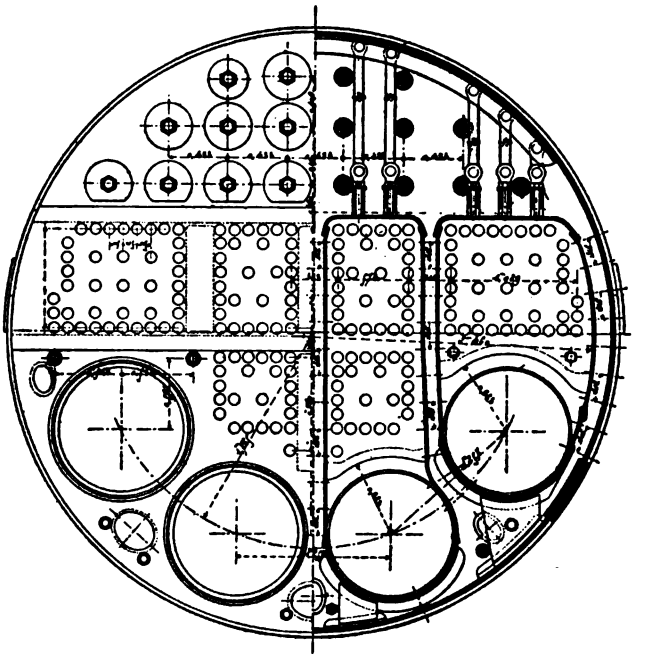

Fig. 53A.

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In some cases there is a single combustion-chamber common to all the furnaces, and from which all the tubes start; in others there are water spaces dividing the combustion-chamber into as many compartments as there are furnaces (Figs. 52 and 52A).

These water spaces add to the heating surface, and, in addition, apportion the flames more equally by confining to each nest of tubes the gases proceeding from the furnace immediately beneath it.

In the mercantile marine this subdivision by water spaces is not often adopted. On men-of-war, on the contrary, the combustion-chamber is generally subdivided. This difference is due to the exigencies of forced draught on men-of-war; with forced draught and a single combustion-chamber, some of the tubes are very liable to excessive heating.

79. *Double-ended Boilers.*—Boilers fired from both ends were first introduced into the mercantile marine, and it is on merchant ships that they are used to the best advantage, that is, with a single combustion-chamber common to both ends and with a longitudinal vertical division down the centre (Figs. 53, 53A, and 53B).

The design is thus very much simplified as it suppresses the water space at the end of the single-ended boiler, where there is apt to be difficulty with the stays.

In double-ended boilers the depth of the combustion-chamber is usually made 1 ft. in excess of the diameter of the furnace. This realises a saving over two single-ended boilers placed back to back, of 1 ft., plus the thickness of two water spaces, plus the space usually left between the boilers, equal to, say, about 3 ft. 3 in. The saving in weight is also considerable.

Double-ended boilers with a single combustion-chamber were especially prone to leaky tubes when under forced draught, and consequently separate combustion-chambers were provided for each end of the boiler (Fig. 54).

If the stoking and forced draught were always equally distributed there would not be the same objection to the combustion-chamber common to both ends of the boiler. However, the two types seem to be used indifferently. It will be seen,

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COLUMBIA.

DOUBLE-ENDED CYLINDRICAL BOILER.

Scale 24 mm. = 1 mètre.

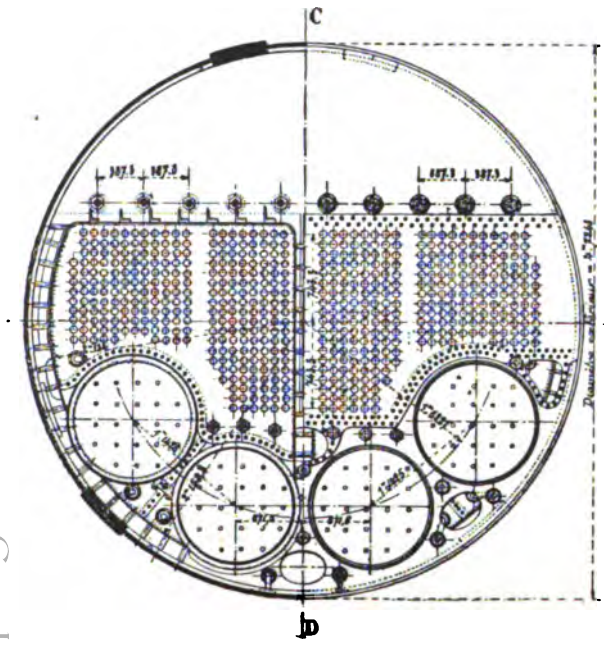

Fig. 54.

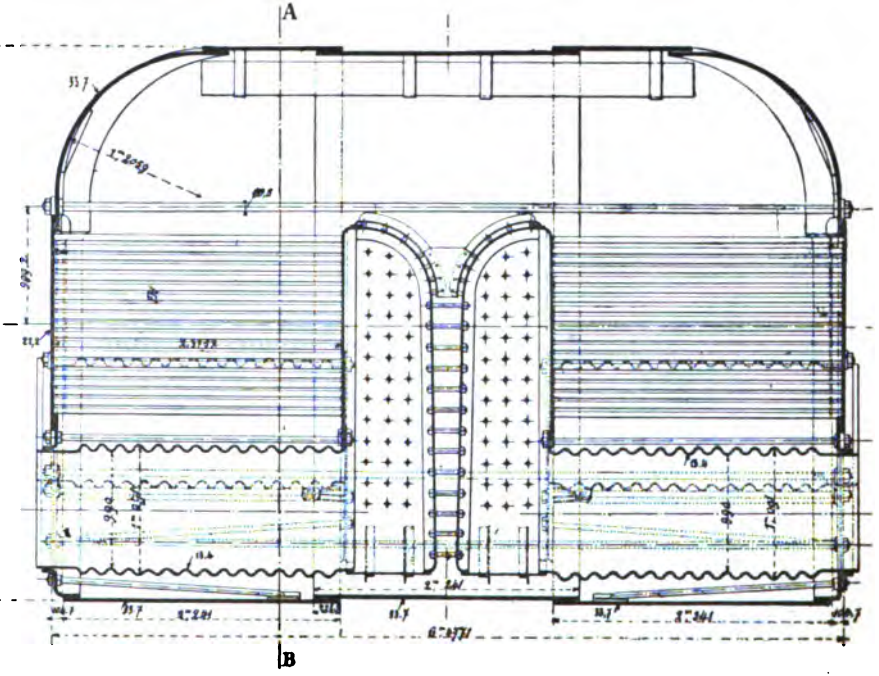

Fig. 54A.

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LINOIS.

ADMIRALTY OR DIRECT TUBE TYPE BOILERS.

Scale $\frac{1}{16}$ of full size.

Horizontal section on A B.

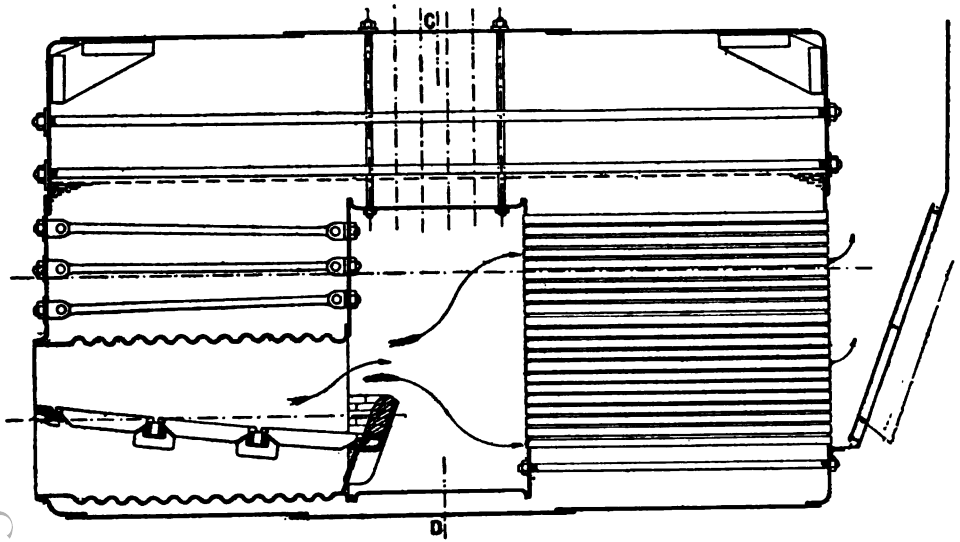

Fig. 55.

Half elevation and half section on C D.

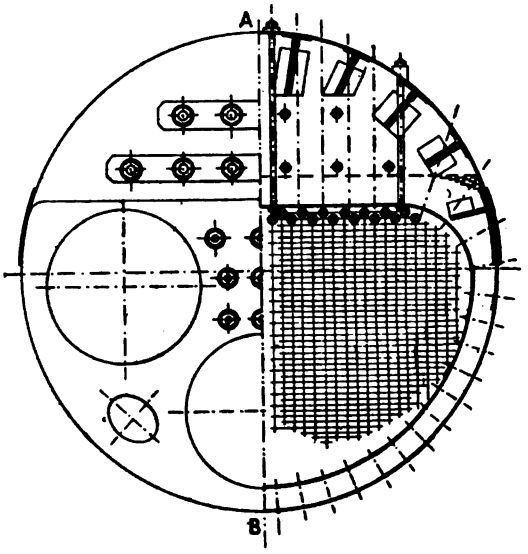

Fig. 55A.

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however, that double-ended boilers on warships lose a great proportion of the advantages, as to space occupied, weight, and simplicity of construction, that they possess on merchant ships.

On certain liners, the *Lucania* and the *Campania*, for instance, there is a common combustion-chamber for the two corresponding furnaces at each end.

80. *Direct Tube or Admiralty Boiler* (Fig. 55).—Instead of placing the tubes above the furnaces, so as to reverse the gases, they may be arranged as a prolongation of the furnace, and at about the same height, but separated from it by the combustion-chamber. This arrangement considerably reduces the diameter of the boilers and enables them to be placed under the armoured deck, where there would not be sufficient head-room for return-tube boilers. Owing to the smaller diameter of the boiler, the strength of the shell is proportionally augmented; the working pressure can, therefore, be increased without thickening the shell-plates. Finally, in the Admiralty or direct-tube type of boiler, the length of the tubes is not limited by the length of the furnace as is the case in the return-tube type.

The disadvantages attending the use of direct-tube boilers are that the hot gases are not so well mixed, and that the tubes are more unevenly heated. The furnace crowns, being very near the water-level, are much more liable to overheating should a fall in the water-level occur. This danger is also greater at the top of the combustion-chamber, which, though not necessarily nearer to the water level, is much nearer to the furnaces and therefore to the hottest gases. Further, on account of the length of the boiler, for an equal angle of inclination, the effect on the water-level is much greater. Finally, the unequal expansion of the various parts of the boiler is more pronounced, especially at the top and bottom, due to the increased ratio between the length and the diameter of the boiler; the local strains are also more severe on account of the comparatively feeble circulation in long and low boilers. For all these reasons, and for others of less importance, direct-tube boilers are only now used in cases of absolute necessity.

In direct-tube boilers the combustion-chamber is necessarily

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BOILER OF THE FLEURUS.

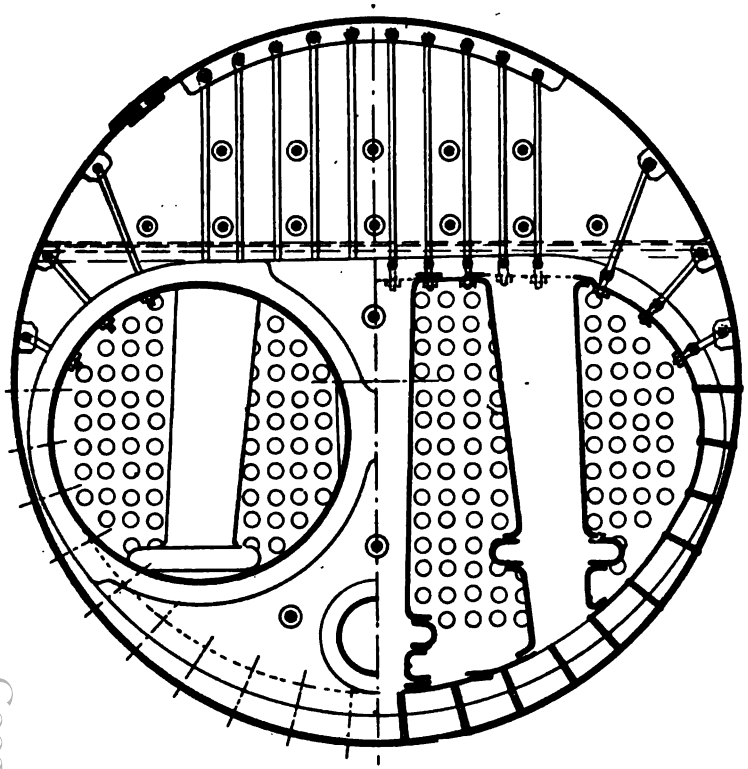

Fig. 56.

BOILER OF THE SURPRISE.

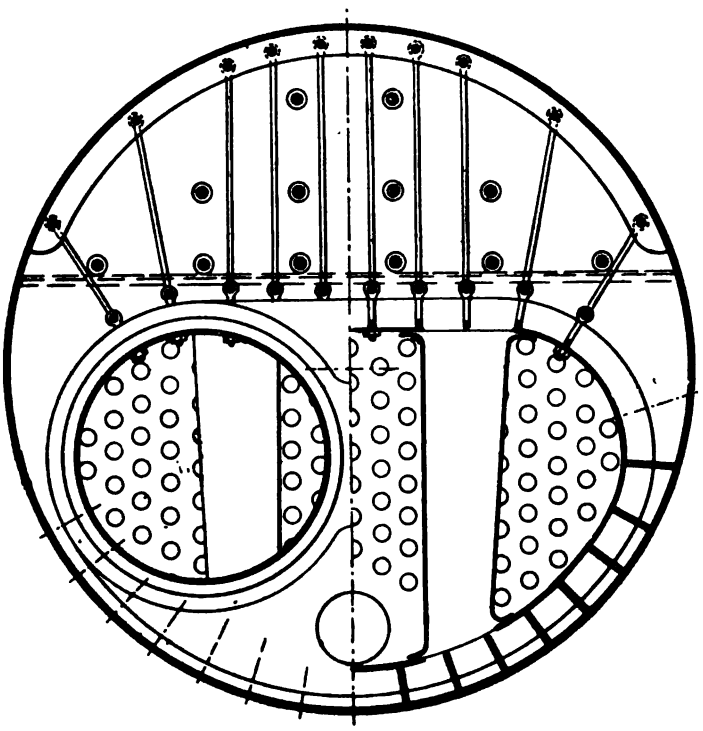

Fig. 57.

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longer than in return-tube boilers, and, when using forced draught, for reasons already stated, but which hold with even greater force, the combustion-chamber of direct-tube boilers should be fitted with water spaces.

Some very unsuccessful attempts have been made to increase the heating surface of the combustion-chamber by interposing water spaces as a screen to the more exposed tubes,* or by fitting large cross tubes. Fig. 56 gives the first installation of this kind on the *Fleurus*, and Fig. 57, that actually in use on the *Surprise*. Baffles or screens composed of fire-brick have also been fitted to several boats to direct the course of the gases, and have the advantage of thoroughly mixing the gases before they reach the tube-plate.

Direct-tube boilers must always be single-ended; there is a simple reason for this, quite outside of the question of length, and that is that it would be impossible to sweep the tubes while under weigh.

The "direct-tube" boiler is generally known as the "Admiralty" boiler, on account of its extensive use in the Royal Navy; in France the use of this form of boiler was for some time limited to gunboats.

When the term "marine" or "marine type" boiler is used in this treatise, it is always with reference to the return-tube boiler.

§ 2. CONSTRUCTION.

81. *Furnaces.*—Each furnace is divided into two parts by the grate; the furnace above, the ashpan below. The furnace itself is of necessity horizontal, but the fire-grate generally has a slope of 1 in 10 towards the back.

This slope, which is indispensable for firing purposes, divides the furnace in a rational and correct manner, as it gives an increasing area for the gases of combustion and a gradually decreasing one for the supply of air. The slope of the grate

* This, at any rate, is what was attempted in the locomotive boilers with rectangular fire-boxes, suggested, no doubt, by the Tenbrinck arrangement. (See Fig. 105.)

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might, perhaps, be increased; but it is limited on the one hand by the necessity for leaving sufficient room under the grate for drawing the ashes, and, on the other hand, by the serious diminution of grate area which would result from any considerable departure from the horizontal. It would seem as if it might be of advantage to give the whole boiler a slight backward slope; but this has not yet been tried.

The length of the fire-grate is arbitrary; it is, as a rule, better to make it shorter than the furnace; in any case, it should not exceed 6 ft. in length. When forced draught is used, and the grate surface has not been definitely determined, it is preferable to keep the length down to 5 ft., and to proportionally increase the draught. The length of the fire-grate is of great importance, more especially when the stokers are not very experienced men. With long fire-grates, the coal is liable to be unevenly distributed over them, the consequent ill-effects of which have already been pointed out.

The fire-doors are pierced with holes and fitted inside with baffles to prevent overheating; they must be capable of being opened and shut very quickly so as to admit as little cold air as possible. Those with horizontal hinges and counter-weights are better in this respect than the ordinary types with vertical hinges and double doors. This point will be further dealt with in Chapter XVI.

There are many different types of ashpit doors, between which there is very little to choose. Note should be taken of the bar placed at the entrance of the ashpit for working the firing tools, which is sometimes made adjustable.

82. *Furnaces Composed of Separate Rings.—Corrugated Furnaces.*—In modern boilers the furnaces are always cylindrical in shape, to resist the external pressure of the steam. The question of the stresses to which their sides are exposed is an intricate one. The cylindrical shape, while keeping the structure in stable equilibrium as regards internal pressures, leaves it in unstable equilibrium as regards external pressures.

Any deformation which causes the interior diameters to vary

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at any one point produces a bending moment which the plates are incapable of resisting, with the result that the deformation continues to increase until the furnace breaks down. Besides, especially in the furnace, there exists an initial cause of deformation, produced by the firing itself, since the upper part or crown is highly heated by the fire, while the lower part is vigorously cooled by the current of air in the ashpit.

The resistance of furnaces to collapsing depends not so much on the thickness of the plates as on the means taken to strengthen them. Deformation cannot take place at the extremities of the furnaces on account of their being riveted

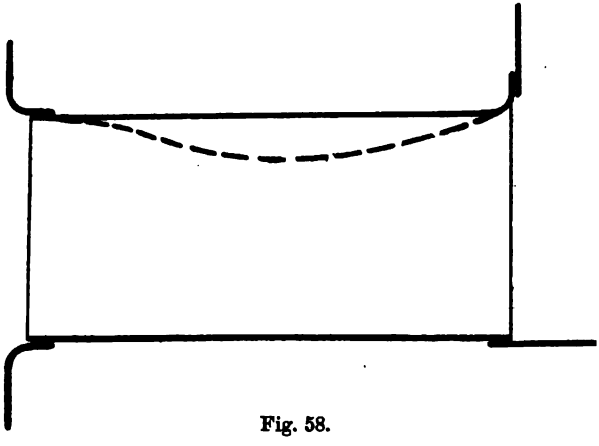

Fig. 58.

to the front and back tube-plates. The effect of these two end-plates is felt over the whole length of the furnace, as any collapsing draws the back and front tube-plates closer together, which the internal pressure of the boiler tends to resist. The correctness of this view may be questioned. Any straining of the attachment of the furnace to the end-plates must have a pernicious effect. It has been urged in favour of corrugated furnaces that they can expand and contract without unduly straining the joints; it is clear that the end-plates cannot be entirely relied upon as a means of preventing collapsing.

External rings of plates and angle-irons are not used to strengthen the furnaces, for the reason that by doubling the

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thickness of metal there is a liability to overheating wherever the plates are not in direct contact with the water. On the other hand, furnaces may well be built up of a series of rings, with their edges turned up and a ring riveted between them and forming ribs, as shown in Fig. 59. The turned-up edges are shown at a and a^1, and the ring or washer at b; this is always used, not so much to add to the strength of the joint as to protect the rivet from the fire by the inner portion of the ring.

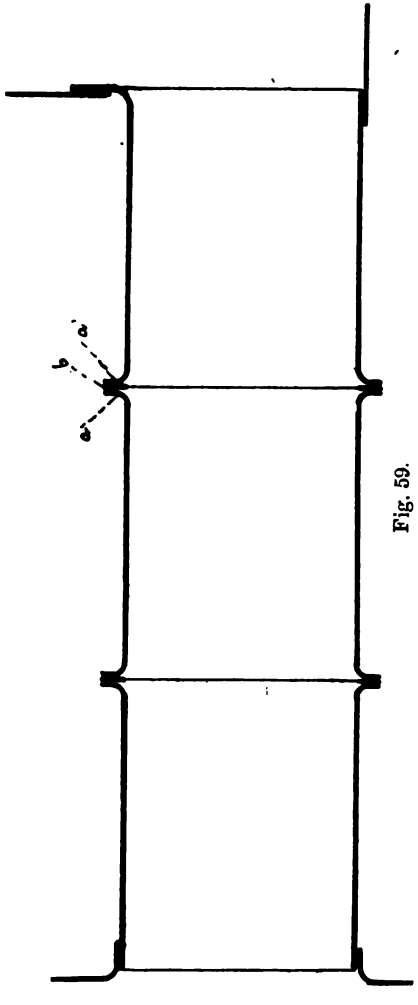

Fig. 59.

Many furnaces are built up in this manner; in well-equipped workshops a special tool is employed for turning over the edges. The rings which make up these furnaces are necessarily without longitudinal seams; the plates are feather-edged and welded together.

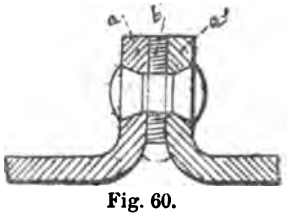

Fig. 60.

The operation of welding is detrimental to the plates (especially when of steel) more particularly where the part that has been raised to a welding heat joins the colder portion of the

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plate; thus furnaces of welded plate are liable to give way, not at the weld, but close to it.

In riveted furnaces, it may be noted that the upper part is placed inside and the lower part outside, as in Fig. 61, to avoid a little inside ledge on which coal would lodge.

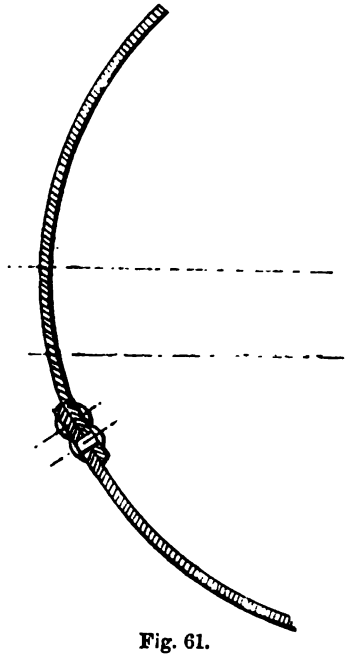

Fig. 61.

As a matter of fact, furnaces are now usually made of corrugated plates, the shape of which offers a certain resistance to bending. The oldest and most extensively used, are Fox's furnaces (Fig. 62), which are wavy in section, with corrugations about half the depth that would be given to flanges. They are carefully made, and the weld, which is very good, is not liable to the weakness mentioned above. For a long time past the Fox furnaces have given every satisfaction; but since pressures have risen to 150, 170, and even 200 lbs. per sq. in., where the depth of corrugations remains unchanged, they do not come up to present requirements, and many cases of collapse have occurred. A noticeable feature of the Fox

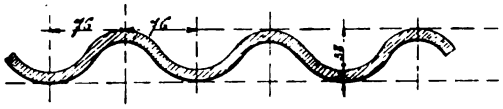

Fig. 62.

furnace is that, owing to its corrugations, and therefore greater elasticity, more pronounced permanent deformation may occur, without serious consequences, than is the case in the ordinary furnace, and the furnace crowns may even drop on to the bars

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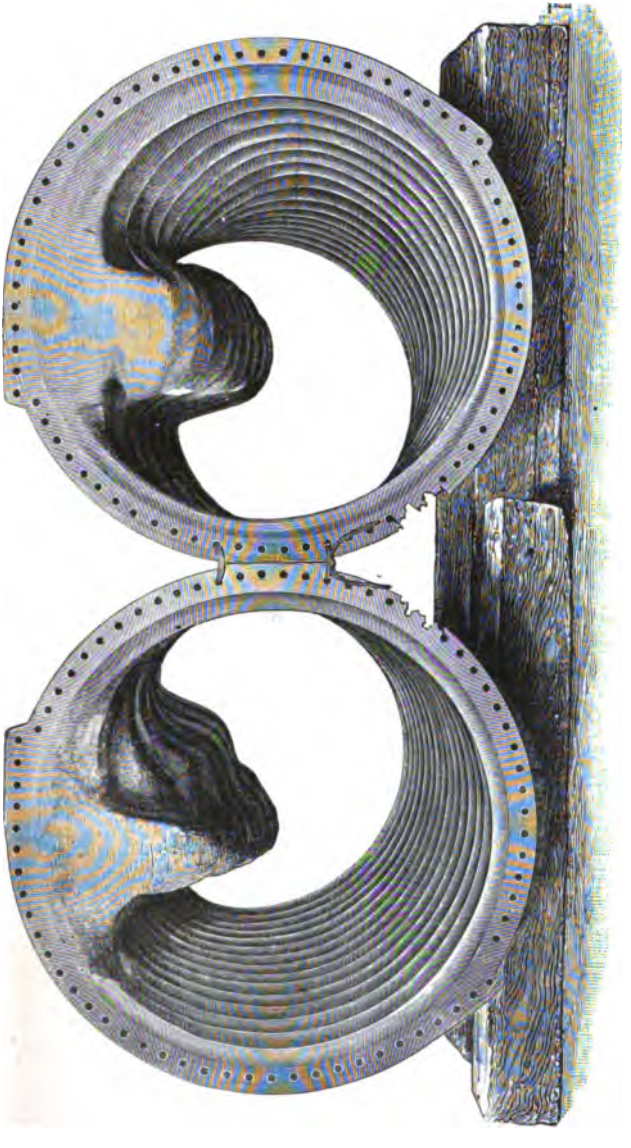

Fig. 63.

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themselves without causing any excessive local strains, or unduly straining the end-plates. This happened on the trial-trips of the *Dupuy-de-Lôme* and the *Wattignies*. Fig. 63, taken from a photograph, shows a pair of the furnaces of the latter ship as they appeared after the trials. As the boilers in question are of the direct-tube type and the crown of the furnaces is very near the water-level, the accident might have been attributed to some overheating owing to shortness of water; but collapses, similar in every respect, have happened on liners with boilers of the return-tube type; any overheating in this case could only have been due to some calcareous or mineral-oil deposits on the crown of the furnace. These excessive deformations have been singularly free from serious results; there was no tearing or ripping of seams or plates, thereby proving the high quality of the materials used.

To guard against these deformations, there is no other way than to carefully watch for any small changes of shape which precede them, and to restore the correct diameter with a screw-jack as soon as any ovalisation is apparent. The subsequent use of the boilers, after undergoing these extensive repairs, testifies to the confidence placed in the Fox furnaces, but there is no guarantee against the recurrence of similar accidents, and the adjoining parts are liable to become strained.

The constant exposure to accidents similar to those which occurred on the *Dupuy-de-Lôme* and the *Wattignies*, has led to the introduction of a modified form of Fox furnace, which, while diminishing the area of the plates, and consequent liability to deformation, maintains a reasonable amount of longitudinal stiffness. With this aim in view, several new designs have been brought out, but the one in most general use is the Purves furnace, shown in Fig. 64, which appears to give good results.

It is evident, however, that no form of furnace can resist overheating when covered by a non-conducting deposit of salts or mineral oil.

Though not much used in France, other methods of strengthening furnaces may be noticed. The furnace may be strengthened by external plate, or angle-iron rings, with dis-

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tance pieces from 1·2 to 1·6 ins. in thickness (Figs. 65 and 65A). These are fixed to the furnace by round-headed bolts, with nuts and washers on the outside. The rings are similar in section to the bridges in common use for supporting the crown of the combustion-chamber. The furnace may be constructed of short lengths of different diameters fastened end to end.* None of these systems appear to afford the security of the Fox or Purves corrugated furnace, provided their corrugations

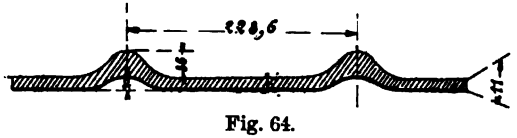

Fig. 64.

are properly designed, as it is a *sine quâ non* that the number of riveted joints directly exposed to the fire should be reduced to a minimum, and the corrugated furnaces fulfil these conditions.

The mode of riveting the furnaces to the end-plates is a part of the construction of a boiler that requires the greatest care and skill; local straining may become excessive, and the slightest leaks give rise to rapid deterioration.

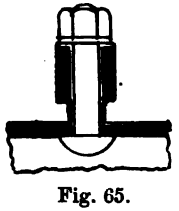

Fig. 65.

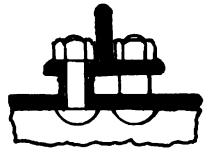

Fig. 65A.

In construction, the furnace is first fixed to the combustion-chamber, which is then attached to the body of the boiler. Usually, the upper part of the furnace is turned up, and riveted to the tube-plate on the side away from the fire. The shape of the bottom-plate enables the turned-up edge of the upper part of the furnace to be introduced into the combustion-chamber with ease (Fig. 66). This arrangement has the advantage of

* See Seaton. "A Manual of Marine Engineering," 1895, p. 425.

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not exposing the edge of the plate directly to the flame. As overheating is not the greatest danger to which the joint is exposed, it being subject to irregular heating and cooling, the contrary arrangement shown in Fig. 66A, is sometimes adopted, and is more convenient for repairs.

The form of joint at the combustion-chamber end allows of a good accurate joint being made; but at the front end of the furnace, where two cylinders have to be slipped one into the other, it is necessary to leave a play of $\frac{3}{32}$nds of an inch all round, and to subsequently expand the furnace to fit the shell.

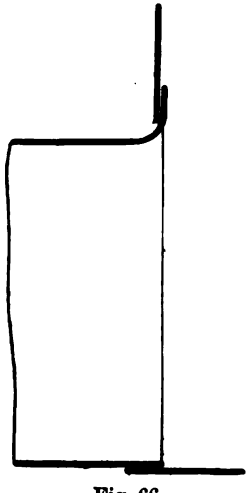

Fig. 66.

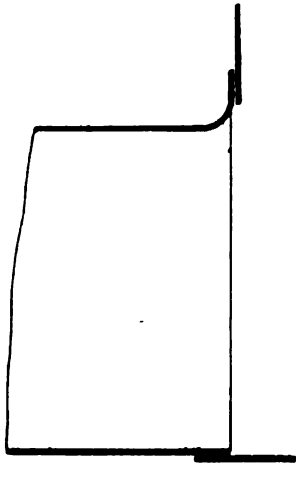

Fig. 66A.

Fig. 67 shows how, in practice, there is a risk of this fit being confined to the front edge of the furnace. To ensure a perfect fit, the collar, formed by turning over the front-plate, should be coned so as to allow the furnace, which becomes coned when expanded, to bear all round (Fig. 67A). Another plan, which is pretty generally favoured at the present time, is to turn the edges of the front-plate outwards (Fig. 67B); this facilitates the stiffening of the furnace, and also the riveting (especially when hydraulic riveters are used). This arrangement is, however, less satisfactory than the preceding one as regards the tightness of the joint when under pressure; it is

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evident (Fig. 67B) that the interior pressure tends to separate the two lips of the joint, whilst, in the form shown in Fig. 67A, it assists and sustains the tightness of the interior edges.

The expanding of the furnace ought always to be done cold, especially if the plates are of steel, as local heating impairs the quality of the steel.

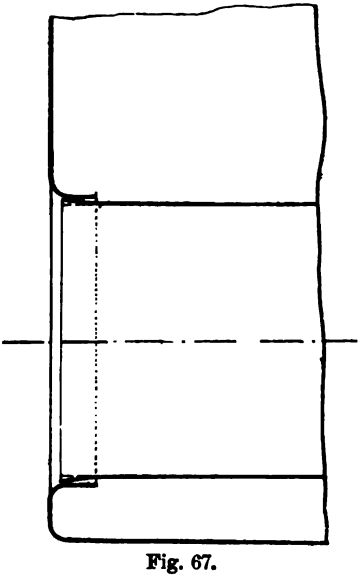

Fig. 67.

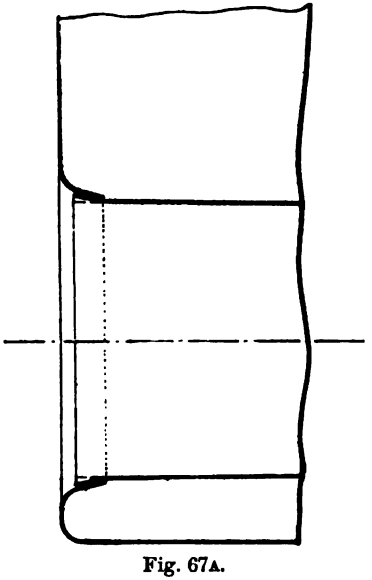

Fig. 67A.

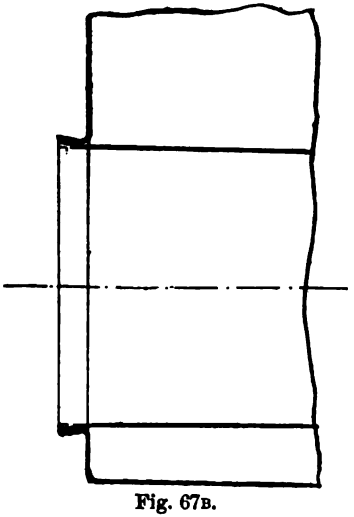

Fig. 67B.

Well-constructed furnaces made of high-class material will last as long as the shells of the boilers. When made of iron plates, they are subject to local damage at the crown, due to the lamination of the plates. In order to make these good, the blistered part is cut out, and a patch is put on, but care must be taken not to make the joint

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with red-lead. In corrugated furnaces, the patches are cut from a plate with similar corrugations. Furnaces as now made of steel are almost entirely free from this form of weakness.

83. *Combustion-Chambers.* — Every combustion-chamber is made up of two flat ends and of a shell, the shape of which varies a good deal according to the different type of boiler. The two end-plates are usually turned over to form the joint; but this is not an invariable rule. Of the six sides of the chamber, the first, that is, the front-plate, is kept in position by the tubes; the second, or crown-plate, is fixed in a special manner; the four others form sides to water spaces, and these will first be described.

The water spaces, composed of flat sides, from 6 to 8 ins. apart, are well able to stand any pressure at present in use, owing to the ease with which they can be stayed. The stays are screwed at both ends and holes tapped in place, thereby forming a very rigid structure.

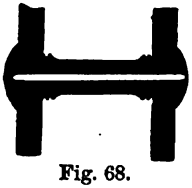

Fig. 68.

In some boilers, especially on those of torpedo-boats of the locomotive type, these stays are made hollow, so that should any of them become rusted through or broken, attention would be drawn to the fact by the escape of steam. On the furnace side, the hole in the stay is very small, thereby reducing the quantity of steam that can escape, and avoiding any back rush of the flames through the furnace doors.

The stays are spaced about 8 in. centres; this is sufficient to obviate any appreciable buckling. They are about $1\frac{3}{16}$ in. in diameter, and the stress, under a pressure of 170 lbs. per square inch, is, therefore, about three tons per square inch. The finer the thread, the greater the strength of the bolt under the thread. This is not made less than about $\frac{3}{32}$nds, for fear of stripping, should the thread become rusted. In addition to the thread, stays are now fitted with a head on one end and a nut on the other; this precaution makes the stay itself tight, but does not dispense with the necessity for tapping the plates, which alone ensures the tightness of the joint as a whole. In combustion-

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chambers, care must be taken not to use any red-lead under the head and nuts of the stays; these will then be better able to transmit heat, and consequently less liable to become overheated.

For a long time it was considered sufficient to simply screw the stays. The stay, after being screwed up in position, was turned over and riveted. The head thus formed, though less liable to overheating, and less exposed, than the present heads and nuts, reduced the tightness of the joint to that of the thread.

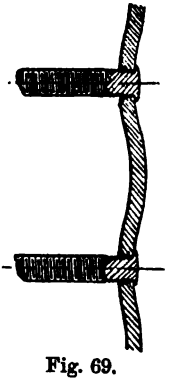

Fig. 69.

When buckling begins, only the outer threads at either extremity of the stay have any grip; this is more particularly the case with fine threads. Fig. 69 is an exaggerated example of the effect produced. Some boiler explosions due to this cause occurred prior to the introduction of nuts and heads.

The stays in compression are always spaced more closely together than those in tension, and by giving the plates more support, enables the thickness of the plates to be reduced; but they obstruct the circulation of the water, and they may, owing to their small distance apart, cause the deposits formed round them to run together and become continuous.

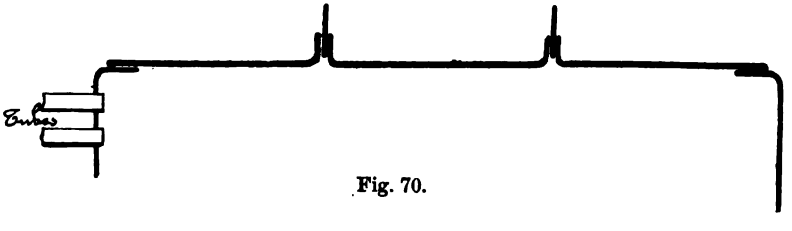

Fig. 70.

The staying of the tube-plate will be gone into when the tubes and tube-joints are under discussion.

The crown of the combustion-chamber, which cannot conveniently be stayed from any neighbouring plates, is subject to high temperatures, and demands special care, as it is the first place in the interior of the boiler to become uncovered

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should the water-level drop; above all things, any staying, by means of plates and angle-irons, necessitating the doubling of the plates, and the consequent danger of overheating, must be avoided.

The crown-plates of the combustion-chamber have sometimes

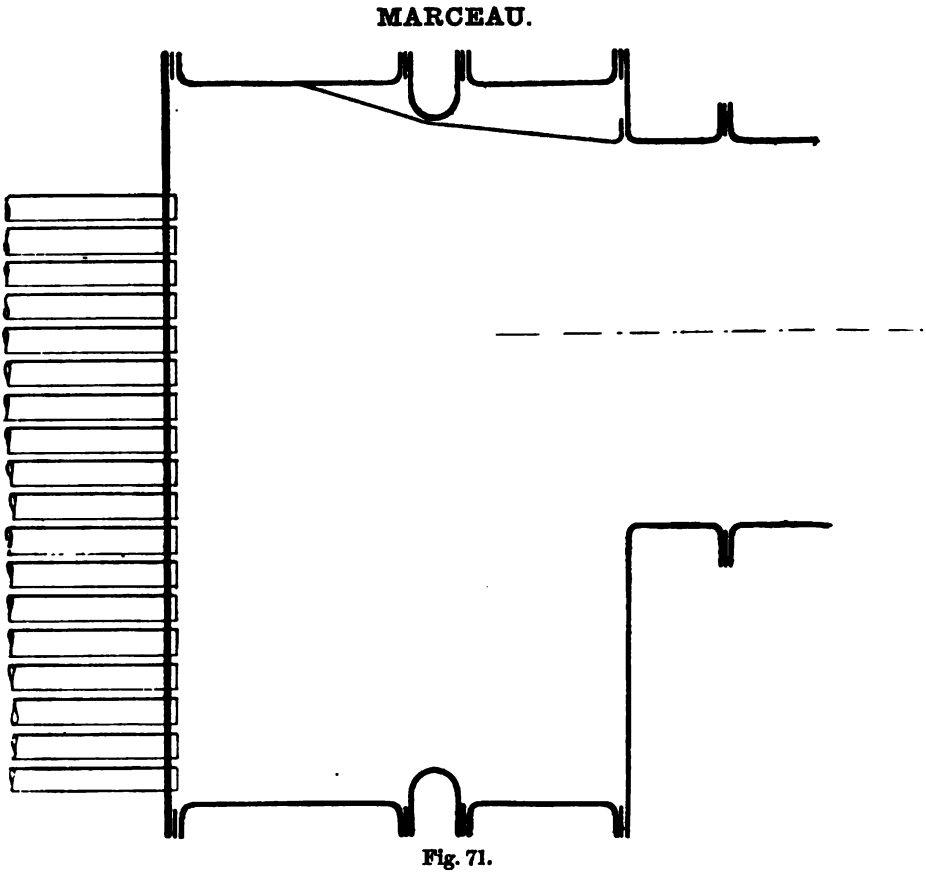

Fig. 71.

been constructed of narrow plates with their edges turned over, and with a vertical ring between them, in a similar manner to the plan adopted in furnaces (Fig. 70). They have even been made of corrugated plates. These complicated arrangements have not found favour, although presenting an important

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advantage, viz., that of allowing for expansion without any deformation of the end-plate, or unduly stressing the tube-joints.

On the *Forbin*, which was fitted with small lead distance-pieces or gauges, a flattening of 0·04 in. was noticed in the ring

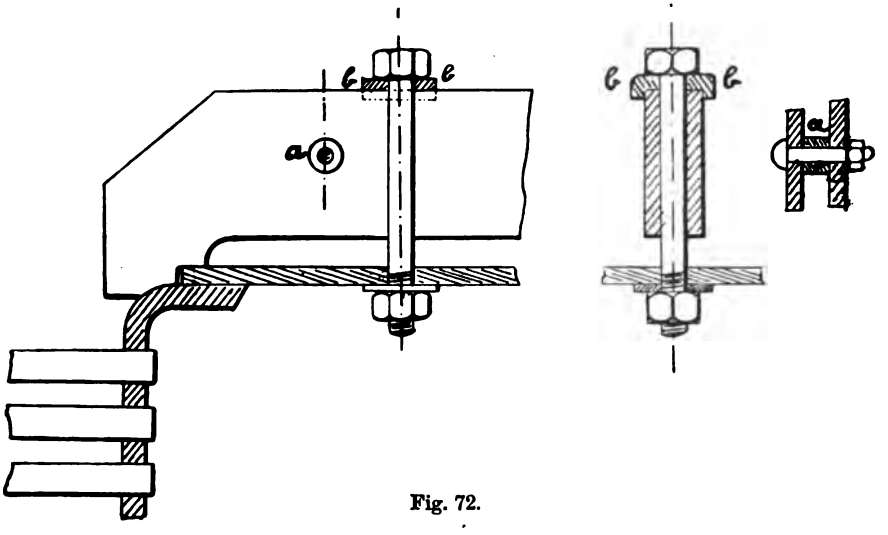

Fig. 72.

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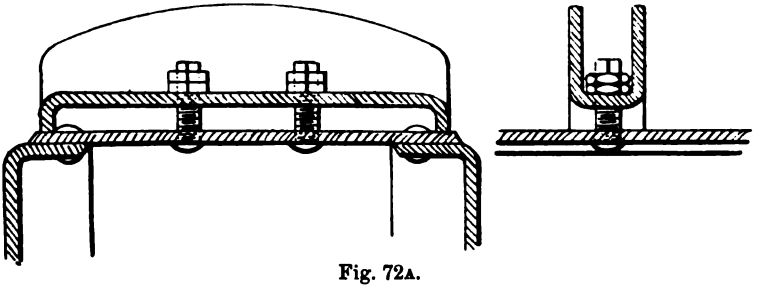

Fig. 72A.

fitted to the crown plate of the combustion-chamber, and buckling in the furnaces to the extent of from $\frac{3}{4}$ in. to 1 in. has been observed. Fig. 71 gives a sketch of the combustion-chamber of the *Marceau*, which is similar to that of the *Forbin*.

In some cases it has been considered sufficient to suspend

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the crown of the combustion-chamber to the shell of the boiler by stays or bolts, screwed into the crown of the combustion-chamber, and fitted with lock-nuts. As these stays expand more than the boiler-shell, and as the combustion-chamber also expands, the stays commence by compressing the crown, and do not support the same until bulging under the steam pressure begins to take place. A certain well-founded mistrust has arisen, which was further increased by the accident that happened, in September, 1894, to the crown of a locomotive type boiler on

CÉCILE.

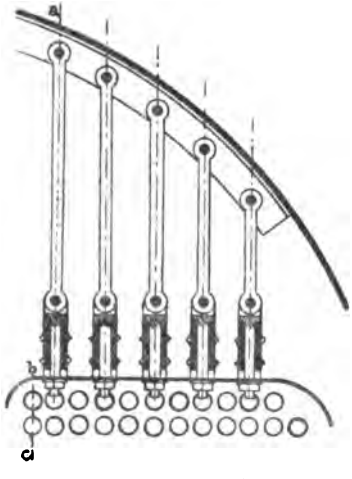
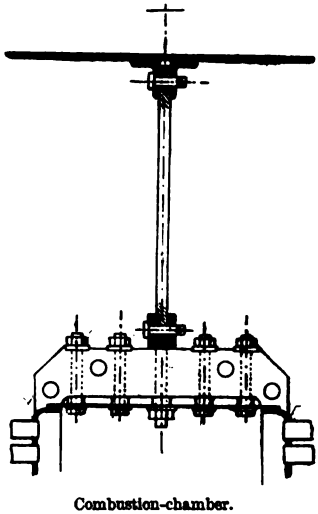


Fig. 73.

Section on *a b c*.



Combustion-chamber.

Fig. 73A.

torpedo-boat No. 120. Owing to shortness of water, the crown bulged, breaking one of the stays, and causing the neighbouring ones to give way in succession.

The most usual arrangement is to support the crown of the combustion-chamber by means of crossbars, clear of the plate, and bearing on the top of the front- and back-plates of the combustion-chamber. To these crossbars or bridges are hung bolts, at suitable distances. The form or design of the crossbars varies sometimes; sometimes they are made of a solid cast-steel plate, thickened where the bolts pass through; more often

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they are composed of two plates, between which pass the bolts (Fig. 72). The two plates are kept from spreading by distance-bolts, as at *aa*, and by small cross plates, with edges turned down, as at *bb*, on which the heads of the bolts rest. The crossbars or bridges are sometimes simply plates bent into the shape shown in Fig. 72A.

The bars or bridges act as rigid girders, transmitting to the back- and front-plates the whole of the pressure on the crown. To relieve these end-plates, the systems of bars, and stays from the shell have sometimes been combined, as, for example on the *Cécile;* but this involved the same drawbacks as attended the use of furnace crown-stays (Fig. 75).

Fig. 54 shows a combustion-chamber, in which the shape of the crown assists in resisting compression.

All the foregoing illustrations are taken from return-tube boilers.

In direct-tube or Admiralty type boilers, where the crown of the combustion-chamber is very close to that of the furnace, and consequently exposed to great heat, the exercise of still greater care in their construction is necessary.

84. - *Various Types of Boiler Tubes and their Spacing.*—Boiler tubes receive the hot gases as they emerge from the combustion-chamber, and it is by their means that a large portion of the heat is transmitted from the fire to the water. Generally speaking, the longer and smaller they are, the better do they fulfil their duty of cooling the flames; the question of their length and diameter is, therefore, intimately connected with that of the efficiency of the boiler. It will be sufficient, for the present, to state that, in practice, their internal diameter varies from 2 to $3\frac{3}{8}$ ins., and that the tendency in the French Navy is to use small diameters.

In regard to construction generally, the important points to be studied are the quality of the metal, the spacing of the tubes, and the type of tube-joints.

Boiler tubes are made of iron, of steel, or of brass.

Iron and steel tubes are cheaper than brass ones, and, as regards the transmission of heat, are in no perceptible way

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inferior to the latter. With a thickness of $\frac{3}{32}$ of an inch, which is that given to brass tubes, they last well, say some three or four years in boilers in constant use. At the present time they are almost the only ones fixed on passenger vessels. Much discussion has taken place on the relative merits of iron and steel tubes, without any very definite conclusion being arrived at. Tubes of rather hard and tough steel possessed this advantage, that they could be taken out without loss of shape and replaced when the ordinary conical mandrel was used to expand them; but, at the present time, owing to the "Caraman" system being employed, the tubes are so accurately fitted in place that they have to be split to remove them, and cannot be replaced until fresh ends have been welded on.

Steel tubes are electro-negative in the presence of iron, and should have, on that account, a shorter life than iron tubes; as a galvanic action, according to some authorities, is said to exist.

Iron tubes sometimes have copper ends welded on to them in order that the expansion, which increases with the temperature, may increase the tightness of the joint. This practice, which principally obtained owing to the employment of copper fire-boxes, is now being discontinued.

The great disadvantage of brass tubes is their price, and moreover at a temperature of about 400° F., they lose a good deal of their strength. Their long life is their chief recommendation; if made of very homogeneous metal they may last out several boilers by being simply re-ended with brass or copper. They have also the enormous advantage of not deteriorating when the boiler is laid up, during which time iron or steel tubes are liable to become pitted and perforated; this last quality renders them peculiarly valuable for use on warships. Further, brass tubes do not give rise to any injurious galvanic action, and their greater expansion does not seem to have any bad effect on the tube-joints. On the *Condor*, iron was used for the stay-tubes, and brass for the ordinary tubes, without any injurious effect on the tube-plate being noticed.

Of late years there has been much discussion as to what metal should be employed in the tubes of warships. For instance, on the *Isly* they are of brass; on the *Davout*, *Cécile*,

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and *Wattignies*, of steel with copper ends; and on the *Hoche* and *Marceau*, of steel alone.

The most unfavourable instance of the use of steel happened

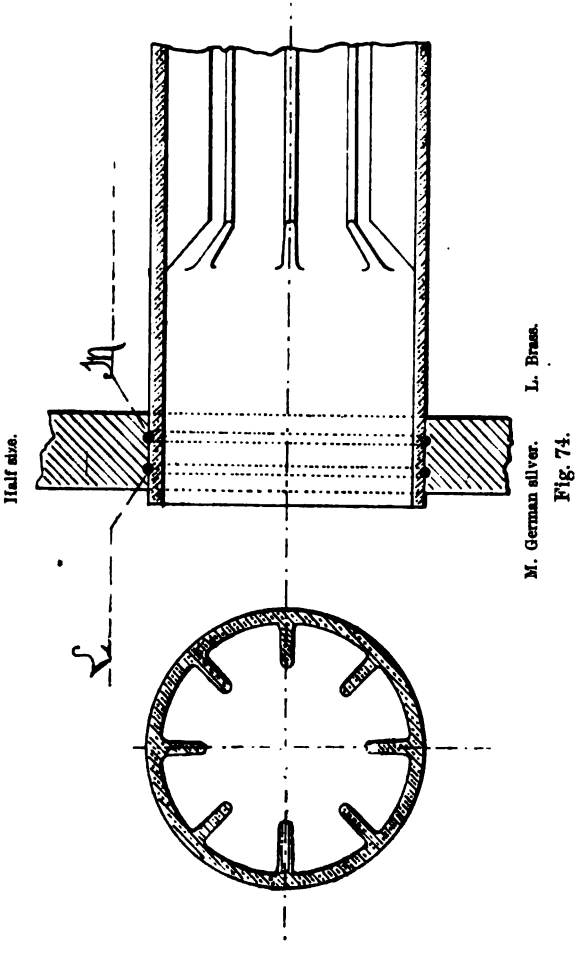

Fig. 74.

on the *Marceau*, where the tubes were found to be badly pitted at the end of the trial voyage to Cronstadt. Since that time, as the precaution has been taken to keep the boilers full of water, slightly alkaline, both iron and steel tubes have lasted longer.

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On merchant vessels, iron or steel is preferred as being less costly; nevertheless, on some American boats they have come back to brass tubes.

It is very important, especially in dealing with steel, that solid drawn tubes should be used, whether drawn from bent plates or from hollow ingots. The mildest quality of steel is the best, say with a breaking strength of 25 tons per square inch; hard steel is inferior to iron. Steel containing 25 per cent. of nickel, which is not affected by sea-water, would form a satisfactory solution of the problem were it not for the difficulty experienced in working it.

In order to increase the area of metal in contact with the hot gases, tubes with internal ribs, or Serve tubes, have been employed, of which sections are given in Fig. 74. With the same diameter, Serve tubes have a heat-absorbing surface 75 per cent. greater than that of ordinary tubes, while the exterior heat-distributing surface remains the same. After many years' experience with Serve tubes on several steamship lines, it has been found that more work is got out of the boiler, resulting in an economy in the consumption of coal per horse-power of 10 per cent.

The ribs of the Serve tubes are stopped within about 12 ins. of the end, to enable a conical, Dudgeon, Caraman, or other expander to be used. (Fig. 74.)

The resistance to bending offered by the Serve tubes has given rise to a fear that their rigidity would cause an excessive strain on the tube-plates. Though during a trial on the *Fleurus* they caused leaks in the tube-plate, on merchant steamers, on the other hand, according to Mr. Ellis, they have been at work under forced draught for several years without being the cause of any trouble; further, on the American locomotives to which they have been fitted, the result was an actual diminution of leaks in the tube-plate.

In tubular boilers the ribs of the Serve tubes are situated where the transmission of heat takes place with the greatest difficulty, hence their efficiency. In tubulous boilers the contrary is the case, and the ribs are of little practical value.

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The *Guébhard* spirals or retarders consist of thin strips of brass twisted into the form of a screw, and when used, are placed inside the tubes. They agitate the gases, causing all the particles to come successively in contact with the sides, without in any way altering the heat-absorbing surface of the tube.

Tubes have sometimes been given a slight initial set or curvature so as to render them flexible and capable of taking up expansion without injury. This arrangement, which is inapplicable to stay-tubes, though it seems reasonable at first sight, does not appear to have been advantageous in any way.

There are two ways of grouping the tubes, one in parallel lines, as shown in Fig. 75A, the other in zigzag.

The latter allows of a greater number of tubes, in the proportion of $\sqrt{\frac{4}{3}}$ or 1·15 to 1, and at the same centre to centre distance, consequently, with the same width of plate between each hole. This arrangement was preferred for a long time, as to obtain the greatest possible heating surface was the only object aimed at, and this caused the tubes to be placed as close together as possible, consistent with the exigencies of construction. Later, more attention was paid to ensuring the escape of the steam bubbles, and at times the tubes were placed farther apart, although some of the benefits of the zigzag arrangement were thereby lost. The rectangular position facilitates the escape of the steam bubbles, the circulation, and consequently the transmission of heat.

As examples of the zigzag arrangement, may be mentioned the boilers of the *Marceau* and of the *Davout* (Admiralty type), as also the cylindrical return-tube boilers which were the orthodox type in 1877. Fig. 75 represents the spacing of the tubes of one of these boilers; the external diameter of the tubes is 3 ins. ($2\frac{3}{4}+\frac{1}{8}\times 2$), the distance, centre to centre, is 4 ins., which leaves 1 inch of plate between each tube. In the *Cécile* (double-ended boilers), the *Hoche* (Admiralty type), the *Goëland* (return-tube), and others, the rectangular arrangement was adopted (Fig. 75A). On the *Goëland's* boilers the tubes are $3\frac{3}{8}$ ins. outside diameter ($3\frac{1}{8}+\frac{1}{8}\times 2$), and are $4\frac{1}{4}$ ins. centre to centre, which only leaves $\frac{7}{8}$ in. of plate between them.

The predominant advantage of a good circulation having been

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now recognised, the rectangular arrangement is generally preferred at the present time. It is even the practice at times to omit a row of tubes vertically over the centre of each furnace in order to facilitate the escape of the steam bubbles formed on the furnace, which appears to constitute one-third of the total steam produced.

On the *Sfax*, where this row of tubes was subsequently removed, it was proved that the priming which took place prior to this being done was thereby entirely stopped.

In America, where only the rectangular arrangement is used, the tubes are placed further apart horizontally than they are vertically. Thus, on the *Minneapolis*, tubes of $2\frac{1}{4}$ ins.

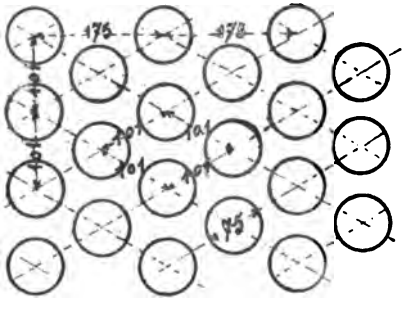

Fig. 75.

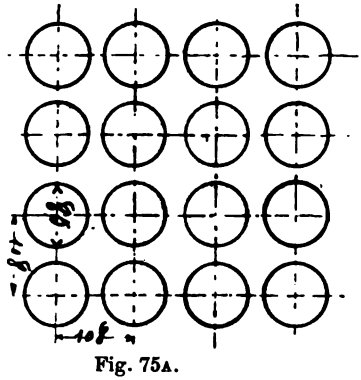

Fig. 75A.

external diameter are spaced 3 ins. centre to centre vertically, and $3\frac{3}{4}$ ins. horizontally.

It will be seen that the tubes cut up the tube-plates until only a third or even a quarter of their original section is left; but it is not such an important source of weakness to the boiler as the presence of the furnace itself.

85. *Tube-joints and their Protection.*—The joint between the tubes and the tube-plate is one of the most intricate subjects in connection with cylindrical boiler construction and demands the most careful consideration.

Formerly, when temperatures did not exceed 250° F., and when pressures did not exceed 30 lbs., when, moreover, forced

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draught was unknown, the holes in the tube-plate were left $\frac{1}{16}$th larger than the tubes themselves, which were by no means always perfectly round. The tube was inserted; it was expanded by a conical drift, driven in with a sledge hammer, and it was then finally kept in place by a slightly conical ferrule, driven into position so as to keep the tube from contracting. On warships the tube was riveted over on the outside, as shown in Fig. 76, but only at the combustion-chamber end.

By this means tight joints were obtained at a comparatively small cost, and the joint was so good, that some engineers were of opinion that stay-tubes were an unnecessary precaution. During this period several kinds of removable or dismountable tubes were successfully employed.

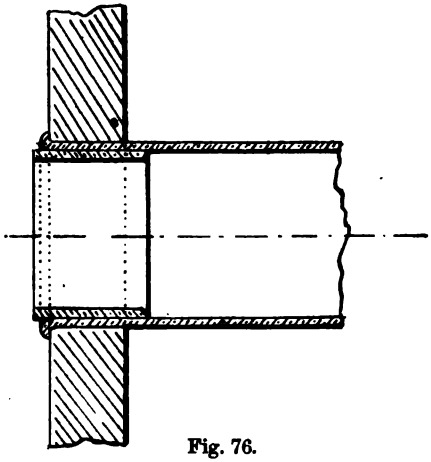

Fig. 76.

With the rise of temperatures in the steam, and especially with the intensity of combustion accompanying forced draught, tube-joints began to give way everywhere. Leakage from the joints rusted the plates, gave rise to what is known as "bird's nesting," and obstructed the tubes; the leaks became, in many cases, so serious that they formed regular streams falling into the ashpan and thence into the stokehold. Here they occasioned more alarm than actual harm, but at the same time necessitated, for the sake of prudence, the immediate lowering of the fires. In some cases this loosening of the joints became a very serious evil, for the escape of steam was strong enough to drive the fires back into the stokehold, even against a forced draught. Luckily, the tubes have always a tendency to protrude through the tube plate instead of withdrawing themselves.

To improve the joint of the tubes with the tube plate, the

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Dudgeon roller-expander was introduced, which, bearing only on three points at a time, was much more powerful than a mandril, which bears all round simultaneously. Thus it became possible to form a shoulder close up to the tube-plate (Fig. 77), an arrangement adopted mostly on stay-tubes. The Dudgeon expander was improved upon by M. Caraman, who placed rollers obliquely to the axis of the mandril, thus forming a self-feeding expander, with which a very large expanding force can be exerted. M. Caraman also uses two circular grooves in the thickness of the plate, into which are inserted two rings, one of brass wire and the other of German silver, which, by the pressure of the mandril, are forced into the metal of the tube (Fig. 78). When the Caraman process is used, there is no

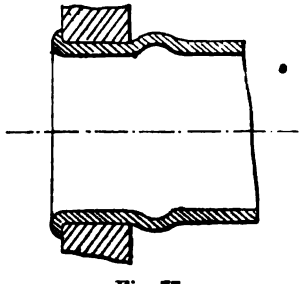

Fig. 77.

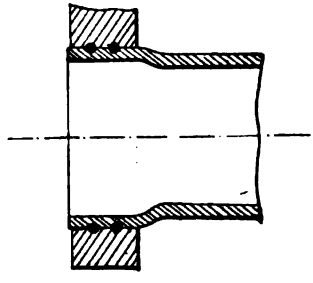

Fig. 78.

occasion to have copper ends on the brass tubes of torpedo-boat locomotive boilers, and stay-tubes may be altogether dispensed with. Tubes expanded on the Caraman system are never riveted over the tube-plate, as the hammering would destroy the effect of the Caraman expander.

By these means tubes can be kept tight under the most intense combustion, provided always that the firing is regular. Many successful four-hour trials have been carried out with tubes expanded on the Caraman or the Dudgeon systems while burning 40, 50, or even 56 lbs. of coal per square foot of grate per hour. But to ensure a complete absence of leaky tubes it is not sufficient that they should be expanded by skilful workmen; the firing must also be done by practised hands, especially in direct-tube boilers, whether of the cylindrical or of

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the locomotive type. The slightest irregularities during firing, such as a furnace door kept open too long, or local thinning of the fire on some part of the grate, giving rise to indraughts of cold air, are always fatal to the tightness of the tubes. The changing of the stokers at the end of each watch is always a critical moment.

All said and done, the perfect tube-joint has yet to be discovered. Ordinary tubes have been screwed similarly to stay-tubes, but the improvement does not warrant the extra cost. Attempts have been made lately to electrically weld steel tubes to the tube-plates, and this may turn out to be a solution of the difficulty when this class of work has been further perfected. Finally, attempts have been made to overcome the primary cause of the accidents which may be briefly described as follows.

The principal cause of injuries to tube-joints appears to be the great difference of temperature existing between the tube-plates and the tubes themselves. The thickness of the tube-plates is sufficient to raise the fire side of the plate to a temperature of 180° F. higher than that on the water side of the plate. In addition, under brisk firing, the plate is kept from direct contact with the water by a compact swarm of bubbles forming a layer of steam behind the tube-plate, while the tube-end, always cooled by conduction, cannot become much hotter than the body of the tube, which is surrounded by water. The tube-plate may, therefore, attain a temperature of 750° or even 850° F. round a tube whose temperature is only 480° or 580° F. at the most. The hole may, therefore, become $\frac{6}{1000}$ths of an inch larger than the tube (supposing it to be of the same material as the plate), and the joint becomes unreliable, however great may have been the pressure originally produced by the expander. Under these conditions the joint is bound to give way should any cooling of the gases occur, for the tube would be affected by it long before the plate.

The failure of a tube joint is almost always attended by a slipping of the tube in the plate, due to longitudinal expansion; this, and the pressure of steam acting on the tubes, have not so far been taken into consideration. When the boiler cools, the tubes come back into place, and the boiler may seem tight even

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under hydraulic pressure, but directly it is put under steam again the leaks reappear. It is necessary, therefore, to lessen as far as possible the difference of temperature between the tubes and the tube-plate. Many means have been tried in order to attain this end.

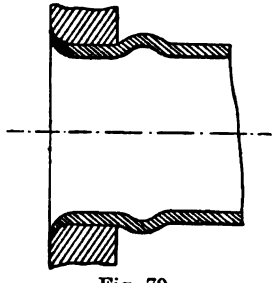

Fig. 79.

On the steamers of the Russian firm, Nobel, which run on the Volga and the Caspian Sea, and which are fired with petroleum, good results have been obtained by avoiding all projection of the tubes beyond the tube-plate, and by turning over the end of the tube within the thickness of the tube-plate (Fig. 79). The stay-tubes, the nuts of which used to burn as badly as the old rivet-heads, were given up, as were also the nuts and washers on the stays.

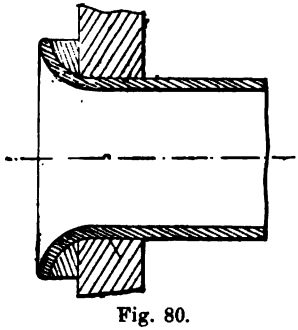

Fig. 80.

In America, the tube-ends have sometimes been projected beyond the tube-plate, and the ends have been turned over a ring of triangular section, as shown in Fig. 80, whereby it was expected that the temperature of the tube-end would be raised.

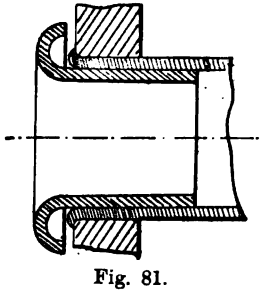

Fig. 81.

In England, on the contrary, the edge of the plate next to the tube has been protected from contact with the fire, thereby keeping down its temperature. After trying an earthenware ring for the purpose, one of malleable cast iron was designed. These ferrules are shown in Fig. 81, several different varieties of which have been brought out.

This class of ferrule has also been used in France. Those fixed to the boilers of the *Fleurus* are shown in Fig. 82. It

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will be seen that the tubes of the *Fleurus* are screwed into the tube-plate. This screwing gives a bad metallic contact and renders the changing of a tube almost an impossibility through the enlargement of the hole after making good the thread.

The result of all this investigation, and of the various attempts to avoid the danger of injury to the tubes at the joints, has been that forced draught has been almost entirely abandoned, as mentioned on page 72, which means that only half the heat which could be produced and transmitted to the water through well-designed tubes is now available in marine boilers, or only a quarter of the heat which the boilers of locomotives will support without injury in the hands of skilful stokers. This want of adaptability to forced draught, owing

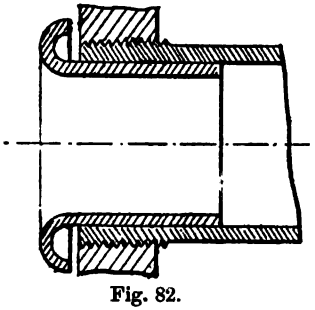

Fig. 82.

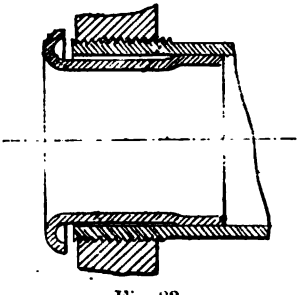

Fig. 83.

to the weakness of the tube-joint, places tubular boilers at a serious disadvantage in comparison with tubulous boilers with accelerated circulation.

The foregoing precautions, though inefficient as joint-tightening devices at the combustion-chamber end, are, on the other hand, superfluous at the smoke-box end. The hole is bored from 0·04 to 0·08 in. larger in diameter than the tube, and it is only necessary to expand the tubes well to ensure a tight joint.

86. *Stay-tubes.*—So far, only ordinary boiler tubes have been dealt with, viz., those intended for the passage of hot gases, and not specially designed to act as stays to the tube-plate, though they do so to a certain extent. Mention may now, therefore, be made of stay-tubes, which. in some instances. have

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been dispensed with in the mercantile marine, while the use of the Caraman system tends to render their employment unnecessary in the Navy.

Stay-tubes are intended to keep the two tube-plates at a

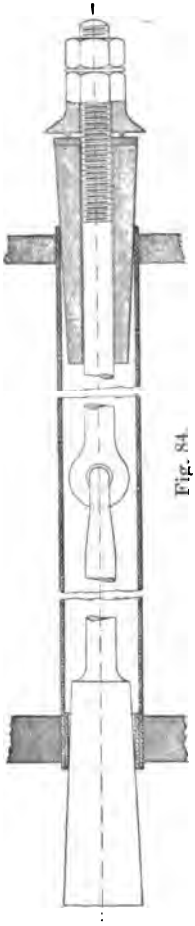

Fig. 84.

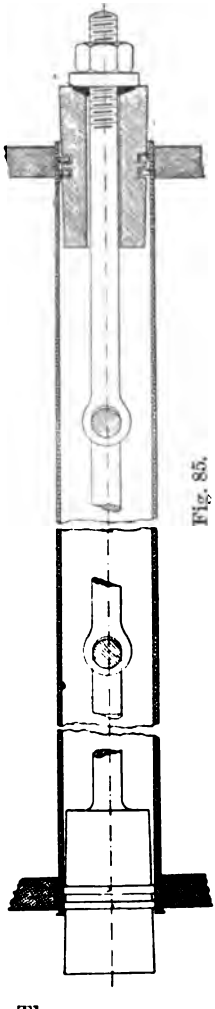

Fig. 85.

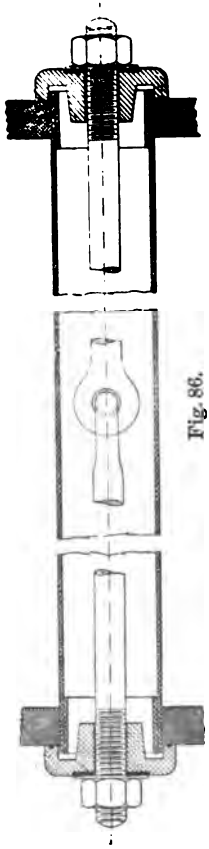

Fig. 86.

fixed distance apart. They are generally made of the same material as the others, but of double the thickness; this increase of thickness is not followed by an increase in the expansion, or any undue straining of the tube-plates.

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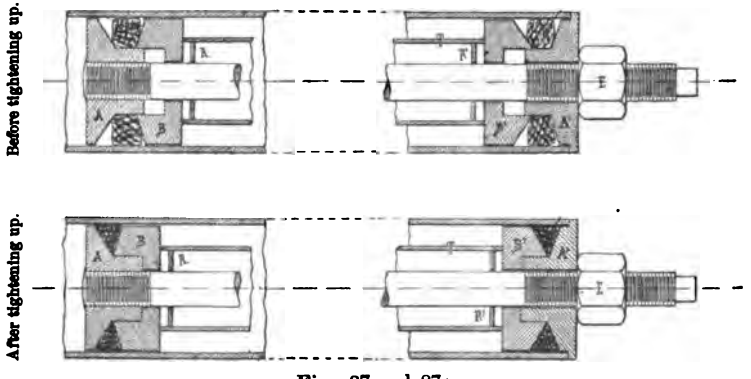
Formerly, stay-tubes were held in position by two nuts on each side of the tube-plate. The present practice is to tap the plates, and nuts are no longer necessary except as lock-nuts A single nut, or even the riveting over of the tube-ends, is therefore found sufficient. The ends of the stay-tubes are thickened about $\frac{1}{16}$th of an in., so as not to be weakened by the threads. From the above, it is evident that stay-tubes are far more costly than the ordinary boiler tubes.

87. *Tube-stoppers.*—It sometimes happens, when boilers are under pressure, that leaks occur in the body of the tubes, either through pitting, defects in the welding or drawing, or by a trans-



Figs. 87 and 87A.

verse crack where the tubes have been re-ended. Formerly, when this occurred, fires were at once drawn, and if there were not time to make immediate repairs, the two ends of the damaged tube were stopped with conical wood plugs driven hard home.

These wooden plugs had an uncertain hold, even in the times of low pressure. With the pressures now in vogue, they are useless. The tube-stoppers at present employed are joined together by a tie-bar, which may be in one or more pieces. Figs. 84, 85, 86 show three different kinds of these.

The first two have a wedge action, and the last makes a tight joint by a pressure on the tube-plate itself. In all three

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cases, as the plugs are inserted at the combustion-chamber end, it is necessary in each case to draw the fires.

To allow of plugging without drawing the fires, M. Houille, an engineer in the French Navy, has invented a tube-stopper, with stuffing-boxes at either end, shown in Figs. 87 and 87A.

The joint is made by means of asbestos rings pressed between two metal blocks A and B, which force the plastic material against the sides of the tubes. The front packing is held in place by the hollow tube T, which is kept central by the rings R R. When the screw E is tightened up, the asbestos is flattened simultaneously at both ends of the tubes.

Another tube-stopper, which obtains the same results by simpler means, but at the loss of some tightness, is that of M. Latil, shown in Figs. 88, 88A and 88B. It consists of a rod at the end of which is hinged a folding plug, which can be passed through the tube, and which opens out or unfolds in the combustion-chamber when pulled into position. At the smoke-box end, an indiarubber washer, pressed between two metal washers, affords temporary protection while the plug is being fixed in position. The fixing of the whole apparatus takes about five minutes.

Tubular boilers have a great advantage over tubulous boilers in that it is possible to plug the tubes of the former without emptying the boiler, while with the latter this is impossible.

88. *Smoke-boxes and the Dangers attendant upon too sudden Cooling.*—On leaving the tubes, the gases of combustion enter the smoke-box, a casing attached to the face of the boiler, from whence they pass into the funnel.

In the smoke-box, facing the tubes, is a large opening, closed by a double flapped door, for the purpose of cleaning or sweeping the tubes. This operation, which has been described in Section 48, is not only very trying to the men and detrimental to the boiler, but also interferes with the draught, as, directly the smoke-box doors are open, the air from the stoke-hold takes a short cut to the funnel. Before cleaning the tubes, fires should be damped to avoid lowering the temperature too suddenly.

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The cleaning process should be done as smartly as possible, and taking each boiler in succession. In some cases the smoke-

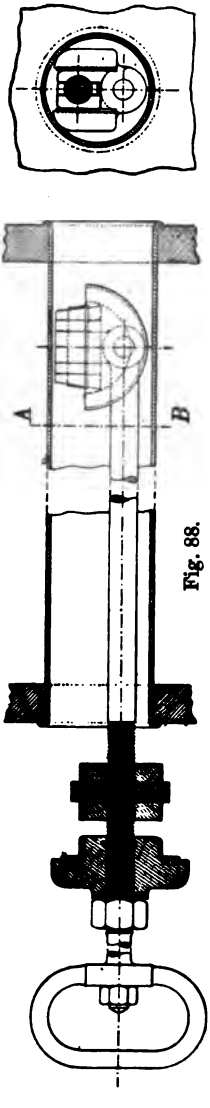

Fig. 88.

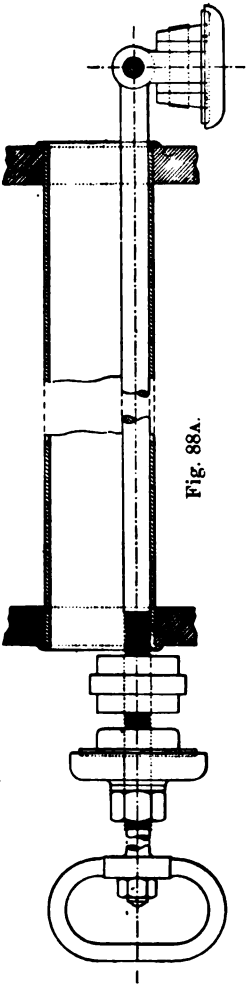

Fig. 88A.

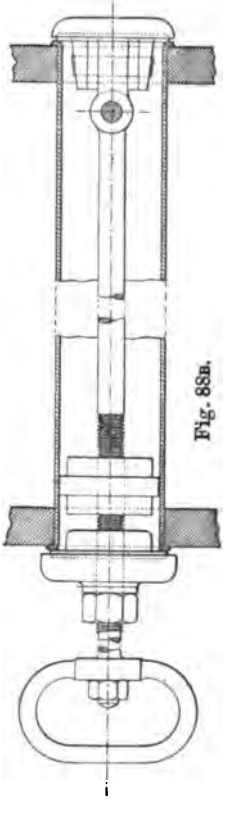

Fig. 88B.

box has been divided up so as to correspond to the number of furnaces. Only one furnace at a time is thus put out of action,

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and, what is more important, with forced draught the furnaces are independent of one another. In these cases a damper is fitted into each division of the smoke-box and prevents any in-draught of cold air through an open door, which would check the general draught of the chimney (Fig. 89). This sensible, though rather complicated, arrangement has not found much favour.

Should the engines be suddenly or unexpectedly stopped, the noisy blowing-off from the safety-valves can usually be

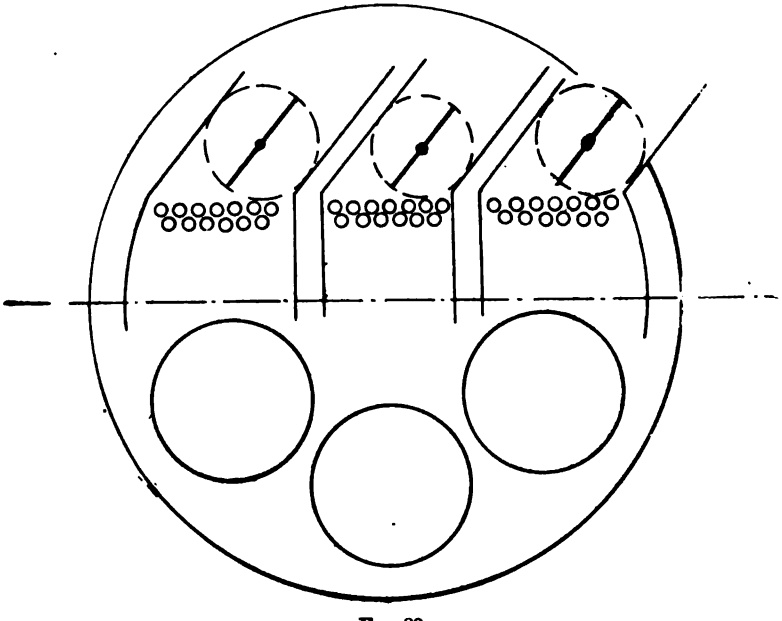

Fig. 89.

checked by opening the smoke-box door. This proceeding, which, for a long time, used to be practised with the greatest recklessness, should be most strictly prohibited on tubular boilers, on account of the strains to which it subjects a boiler when steaming hard. The terrible accident to the boiler of the *Revanche* must not be forgotten, where, through the opening of the smoke-box doors, the steam dome suddenly gave out.

At the present time the smoke-box, like the funnel and uptake, is not made an integral part of the boiler proper, but

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is simply attached to it. This used not to be the case on rectangular boilers, where the top of the smoke-box passed through the steam space, and the abandonment of this arrangement has very much simplified boiler construction.

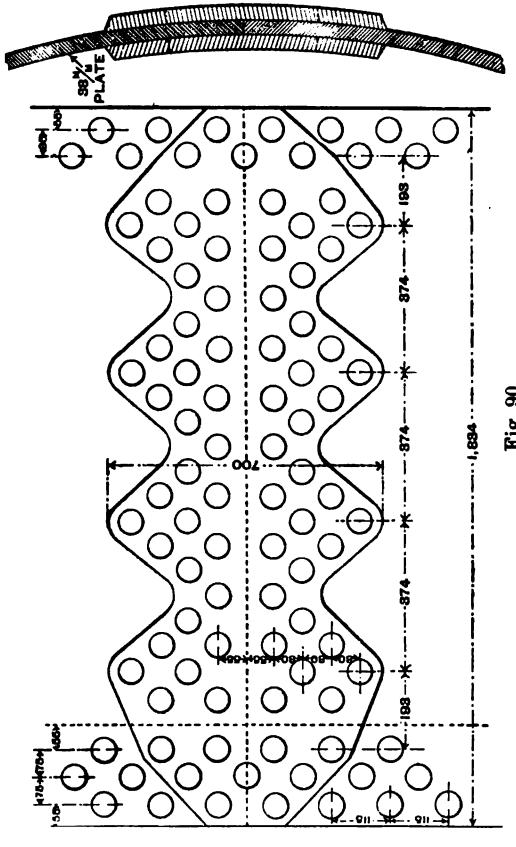

Fig. 90.

89. *Boiler Shell.*—The various interior parts of the boiler just described being heated on one of their sides or faces by the products of combustion, while on the other they are in contact with the steam and water, are in compression. The boiler shell, which is exposed to the atmosphere on one side and to the steam and water on the other, is in tension.

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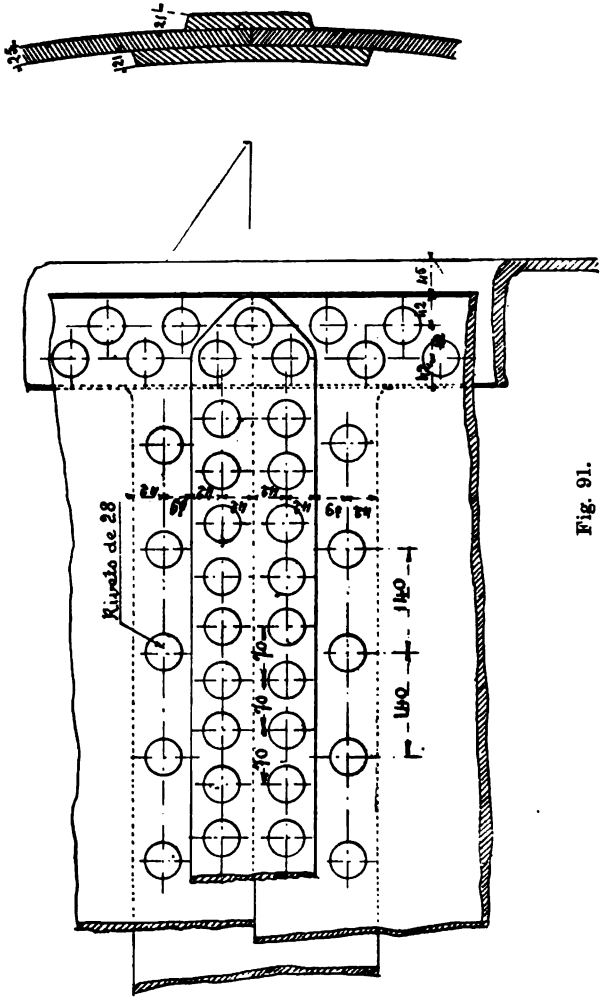
The boiler shell is composed of two parts, the one cylindrical, which constitutes the shell proper, and the other flat, namely, the front and back.



REDOUTABLE.

EXAMPLE OF A LONGITUDINAL BUTT-JOINT IN A BOILER SHELL.

Fig. 91.

The shell is the most important part of the boiler, and has to bear the greatest strains. It is the only part where the strains can be at all estimated approximately, or where

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any comparison with those existing in other boilers can be established. In tubular boilers the stress on the shell-plates limits the pressure at which the boilers can be worked. Fifteen years ago the thickest iron boiler plates made were $1\frac{3}{16}$ths ins., while in steel they are nowadays made up to $1\frac{3}{8}$ths or $1\frac{7}{16}$ths ins. or even higher.

Particular attention has been paid to the longitudinal seams of the shell, in order to give them at least 80 per cent. of the strength of the solid plates, and they are nearly always butt-jointed, with double butt-straps. There are generally four or six rows of rivets, two or three on either side of the seam, every alternate rivet being usually omitted in the outside rows. The size and spacing of the rivets is determined according to the usual rules laid down for riveted joints.

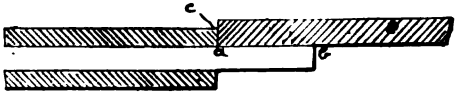

Fig. 92.

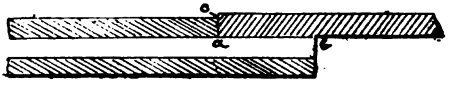

Fig. 93

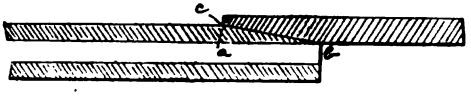

Fig. 94.

The transverse joints, which are subject to lower strains, are usually lap- or scarf-jointed and have two rows of rivets.

The joint where the longitudinal and transverse seams cross one another, may be made in different ways. Fig. 92 gives the simplest, but not the strongest, form in general use. The inside longitudinal butt-strap is generally made continuous throughout the total length of the transverse joint, as shown in Fig. 93, thus increasing the length of the longitudinal joints fitted with double butt-straps by the distance *a b*. As the rivets nearest to the ends of the butt-strap are liable to particularly excessive strains, and as the caulking at *c* is very difficult to keep tight, the arrangement shown in Fig. 94 may be used with advantage, as the plates have no tendency to slip at the caulked joint *c*.

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The ends of the inside butt-straps which come between the two plates of the shell are splayed out, as shown in Fig. 94A.

On the flat ends of the boiler the joints are double riveted, and are always much stronger than the solid plates themselves, as these latter are weakened by the openings of the tubes and furnaces. Boiler-ends stamped out, as they sometimes have been, of one piece, may be looked upon rather as a

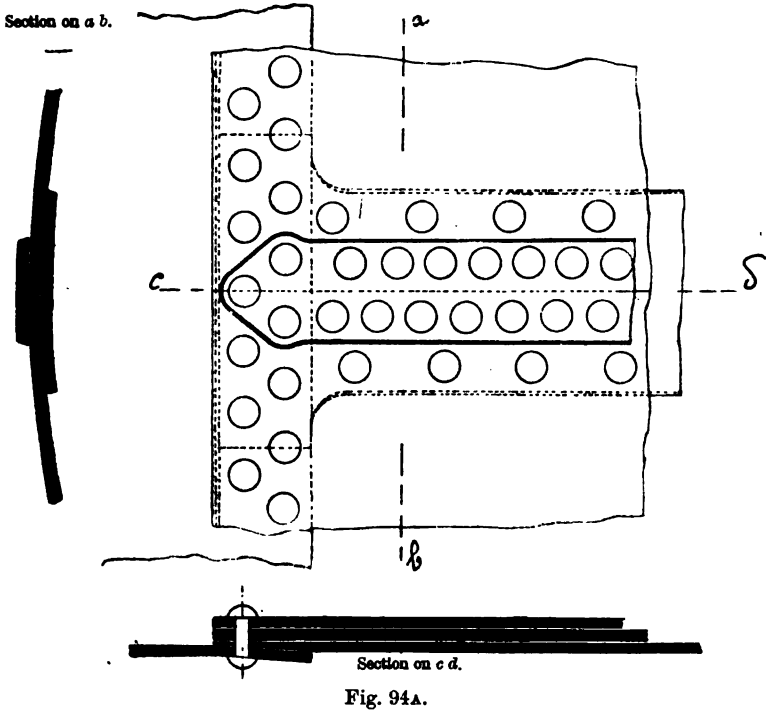

Fig. 94A.

feat of manufacture than as fulfilling the conditions dictated by the necessities of construction.

The upper portion, and some parts of the lower portion, of the boiler-ends, where not stayed, as in the steam-space, are held together by tie-bolts calculated to bear the whole pressure of the steam. These tie-bolts are generally spaced about 16 in. apart, leaving room for a man to pass. They are fastened to the plates by two nuts, one inside, the other out. The

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interior nut is provided with a washer only, a good red-lead joint being made between it and the end-plate. Red lead in this position is not objectionable. The exterior nut, which takes all the strain, bears on a large, thick plate, often riveted to the shell and strengthening it locally so as to prevent any bulging of the main plate in the vicinity of the bolt.

The boiler-ends are turned over so as to make a joint with the shell-plates. Fillets are used with as large a radius as possible, in order not only to relieve the strain on the plates, but also to give to the joints between the end-plates and the shell a certain amount of elasticity, or rather flexibility, to

MARCEAU.

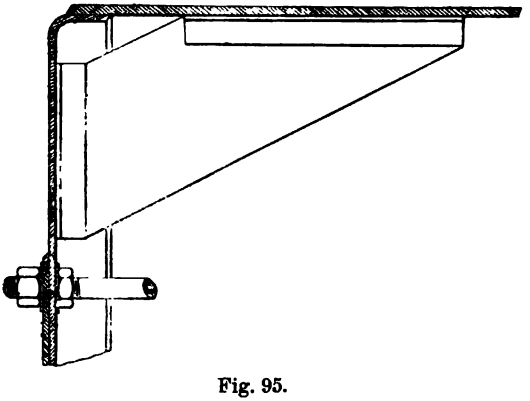

Fig. 95.

which considerable importance is attached in high-class boiler-work.

Sometimes the shell- and end-plates are stayed together by gusset-plates and angle-irons so arranged (Fig. 95), as not to fit all the contours of the joint, whereby the work is much simplified. These gusset-plates make the joint very rigid and do away with all the elasticity of the fillet; their usefulness is, therefore, more than doubtful, and, indeed, they are seldom employed at the present time. The edge of the end-plates at the joint with the shell is now, as a rule, turned outwards as shown in Fig. 96, and hydraulic riveting is thereby much facilitated.

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The riveting of boiler shells, though following the ordinary accepted rules for riveting, must be done with great care, and almost entirely by hydraulic machinery. Stationary riveters are employed on the cylindrical shell and at its junction with the end-plate. For the front and back portable riveters with deep gaps are used, one arm of which is inserted into the furnace mouths; the furnaces, if arranged as in Fig. 67, are riveted to the ends by hydraulic riveters. The work of the hydraulic riveter can be regulated to a nicety. The total pressure exerted on the rivet should be about 95 tons to the square inch; if the pressure be too small, the rivet is badly closed, the hole is not completely filled, and the plates are not well brought together; if the pressure be too great, the metal spreads between the two plates and keeps them apart, as shown in Fig. 97. To avoid this defect a concentric die holds the plates together while the rivet is being closed.

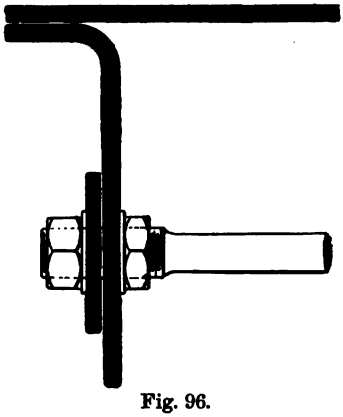

Fig. 96.

The caulking of the shell-plates, indeed the work on every part of the boiler as a whole, requires very great skill on the part of the boiler-makers. The work is a deafening one in the shops, and particularly awkward for the men who have to work inside the boiler itself. Of late, small pneumatic riveters and caulkers, worked by compressed air, have been introduced, which, by a series of blows in quick succession, considerably reduce manual labour and the amount of noise.

90. *Strength of Boiler Shells.—Stress on Materials.—Unequal Expansion.*—It is only in the case of cylindrical shells that reliable calculations of the stress on the material can be made, and, by assuming hypothetical conditions, the formulæ become very simple. It is usually taken for granted that the back and front do not in any way assist the shell against bursting

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pressure, and also that any increase of diameter is uniform throughout its length, so that the shell-plates are uniformly stressed throughout. Let

l be the length in inches,

d the diameter in inches, and

t the thickness of the shell-plates in inches; let, also,

P be the pressure in the boiler in lbs. per square inch, and,

T the tensile stress on the material, per unit of length, in lbs. per square inch.

The total load on the shell-plates is therefore:

$$l\,d\,\mathrm{P}.$$

The resistance is: $2\,l\,t\,\mathrm{T}$.

From which it follows that: $2\,t\,\mathrm{T} = d\,\mathrm{P}$.

$$(1) \qquad \mathrm{T} = \frac{d\,\mathrm{P}}{2\,t}.$$

Though not exact, it may be assumed that the values of T, obtained in this way, are at any rate proportional to the maximum load, and can therefore be compared on different boilers. Equation (1) gives:

—	P Lbs. per Sq. In.	d Ins.	t Ins.	$\frac{d\,\mathrm{P}}{2\,t}$	—
Return-tube boilers.					
Cécile. . .	103·1	176·4	0·925	98·3	The formula does not take into account the resistance of the overlapping of the plates Δl which must be added to l; *i.e.*— $\mathrm{T} = \frac{d\,\mathrm{P}}{2\,t} \times \frac{l}{l + \Delta l}$. This correction is, however, not generally made.
Isly . . .	135·1	118·1	1·181	67·54	
Marshall boiler	160·0	150·8	1·094	110·3	
Direct-tube boilers.					
Marceau . .	85·34	137·8	0·866	67·9	
Davout . .	159·3	115·7	0·905	101·8	
Wattignies .	160·0	113·0	0·905	99·8	

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Tensile stresses, which are not comparable in different types of boilers, vary in a singular manner in boilers of the same type.

Of late years the values of T have been greatly increased. This addition to the tensile strains, while not endangering directly the strength of the shell, may give rise to excessive straining of the internal parts of the boiler.

The increase in the diameter, taken as uniform, would, under the premises stated, be represented by the equation:

$$(2) \qquad d \times \frac{T}{E} = \frac{d^2 P}{2 t E},$$

where E is the modulus of elasticity.

Under the hydraulic test, which usually amounts to 2 P when P is below 85 lbs., and to P + 85 lbs. when P is above 85 lbs., it is found that, in the centre of the boiler where the measurements are noted, the increase of diameter is greater than is given in equation (2), and may be as much as 0·001 *d*. Now an increase of $\frac{3}{16}$ths of an inch in a diameter of $\frac{3000}{16}$, or 15 ft. 7½ in. diameter boiler, would cause the tube-plate to move considerably in those parts where nearly the whole width of the plate has been cut away, and the crown of the combustion-chamber would be considerably strained where stayed.

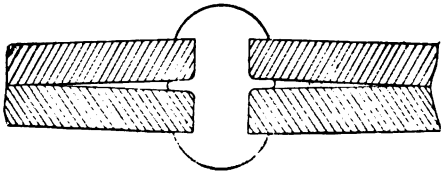

Fig. 97.

If the shell-plates had only to resist a tensile strain in a direction perpendicular to the axis, the expansion per unit of length in this direction, $\frac{T}{E}$, would be followed in the direction of the axis by a proportionate contraction $\frac{T}{E} \times \frac{1}{\mu}$. The coefficient μ is generally taken as equal to 3. When, therefore, $\frac{T}{E}$ amounts to 0·001, the contraction $\frac{T}{E} \times \frac{1}{3}$ is a quite appreciable quantity, and would be represented by $\frac{3}{32}$nds of an inch in a direct tube or Admiralty boiler $\frac{9000}{32}$, or 25 ft. 5¼ in., long.

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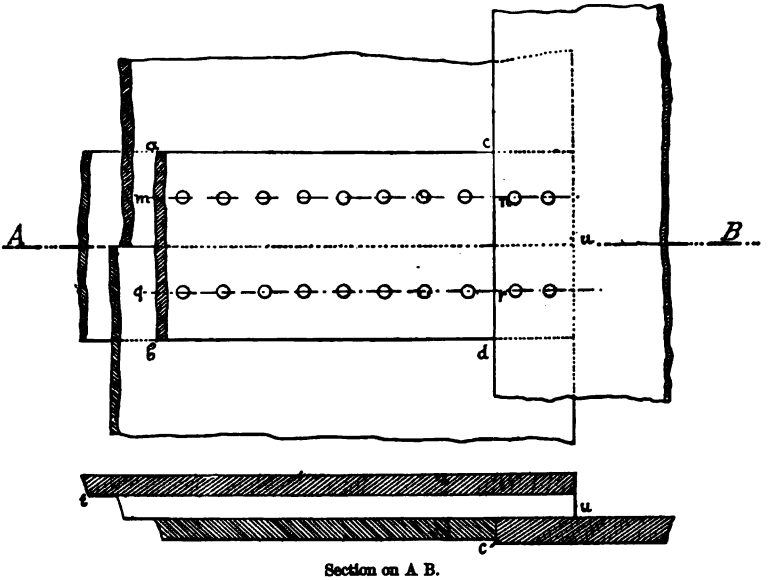
No general diminution in the length of the boiler has been noted to the knowledge of the Author. Indeed the shell undergoes a longitudinal tensile strain caused by the end-plates, which tends to neutralise any shortening action. But there are partial contractions which explain, in a sufficiently plausible manner, certain local strains which show themselves, for instance, by very slight leaks at the ends of the longitudinal butt straps. Take the longitudinal butt strap, *a*, *b*, *c*, *d* (Fig. 98), which butts at *c*, *d*, on the adjoining ring of the shell; suppose it to have a single row of



Section on A B.

Fig. 98.

rivets on either side of the joint *t*, *u* (for this will not affect the argument), *m*, *n*, and *q*, *r*, are lines through the centres of these rivets. The part *m*, *n*, *q*, *r*, of the butt strap is affected by the extension $\frac{T}{E}$, and, consequently, by the general contraction of the butt strap lengthways proportional to the coefficient μ. But, as the two parts *a*, *c*, *m*, *n*, and *b*, *d*, *q*, *r*, which are unstrained, do not alter in length, they have a tendency to force the adjoining ring at *c*, *n*, and *r*, *d*, and thereby to cause a leak

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at n and r. Other parts of the boiler might be selected where a pulling effect is observed; but the above is the best established proof of those partial actions to which reference has been made.

The end-plates tend to produce a strain on the shell in accordance with the formula $\frac{1}{4} \pi d^2 P$.

In a boiler without stays the whole of the pressure would be transmitted to the shell, which would, therefore, bear a tensile strain T_1 determined by the equation:

$$\pi d t T_1 = \tfrac{1}{4} \pi d^2 P. \tag{3}$$

$$T_1 = \tfrac{1}{4} \frac{d}{t} P = \tfrac{1}{2} T. \tag{4}$$

Instead of contracting, the shell would, therefore, expand in the direction of its axis by an amount equal to:

$$\frac{T}{E}\left(\tfrac{1}{2} - \frac{1}{\mu}\right) = \frac{T}{E} \times \frac{1}{6}. \tag{5}$$

In actual practice the stays take almost all the end thrust, and the shell only bears one-sixth of it at most; it is, therefore, only the stays that lengthen.

The exact analysis of the strains in the cylindrical shell is difficult enough, but those of the two end-plates baffle all solution. It has been assumed that the two ends do not affect the transverse strength of the boilers; there is an evident want of agreement between this hypothesis and the one which assumes that the cylindrical shell expands uniformly.

Unless the rounded-over portions of the end-plate give, the uniform expansion of the diameter of the shell, along the whole length of the boiler, would bring on to the end-plates (even supposing them whole and not cut out at all) strains per square inch considerably higher than those in the shell. Under the hypothesis assumed, both the ends and the shell-plates expand in the proportion $\frac{T}{E}$; but they expand in all directions, instead of expanding in one direction and contracting in the other, by the quantity $\frac{T}{E} \times \frac{1}{\mu}$.

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Under these conditions the total load on the end-plates T_1 is given by the equation :

$$T_1 = T \frac{\mu}{\mu - 1} = \frac{d\,P}{2\,t} \frac{\mu}{\mu - 1}; \tag{6}$$

taking $\mu = 3$:

$$T_1 = \frac{3}{2} T. \tag{7}$$

Owing to the cutting away necessary for the tubes and furnaces, the end-plates would be quite incapable of resisting such a tensile strain. Now, neither at the back nor in the front do any of the plates, or even the rivet-joints, ever show any signs of distress, even in boilers where the gusset stays described above prevent any movement at the joint between the ends and the shell. The natural conclusion to be drawn from this is, that the ends are only very slightly expanded. It is not difficult to see why this is so. In reality the expansion of the boiler, in the direction of the diameter, is anything but uniform ; it may amount to $0 \cdot 001d$ in the centre part, but it is very much less at the end ; the shell, in changing shape, takes the form as shown in Figs. 99 and 100. The cause of this difference in the expansion (in the direction of the diameter) lies in the resistance of the ends ; it may also, probably, be due to the deformation to which the ends are subject under the action of pressures parallel to the axis. The end-plates, indeed, have a tendency to sag round the stays, and this should lessen their diameter. It is not beyond the range of possibility that the shells, near their extremities, are subject to slight reductions of diameter, instead of to an increase ; this is shown in Figs. 99 and 100, in which the line m, n, represents the original shape of the boiler before deformation takes place. In this latter case the total tensile strain on the shell, expressed by the equation :

$$2\,t\,\Sigma\,T\,dl = l\,d\,P,$$

would be the resultant of variable tensile strains T, of which the greatest value would be very much larger than $\frac{d\,P}{2\,t}$.

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The preceding considerations show the advantage of allowing some change of shape at the joints between the shell and the end-plates, so as not to force the former to bend, in the manner indicated in Fig. 99, by sagging.

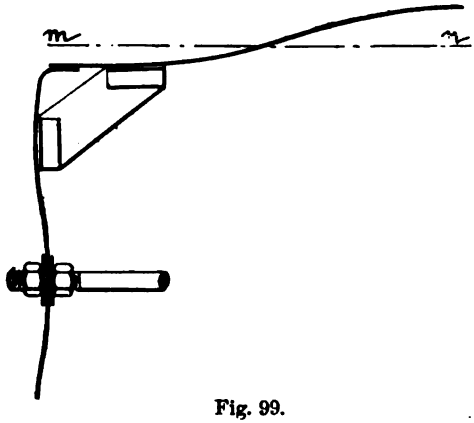

Fig. 99.

There is nothing to be learnt, even for the sake of mere comparison between one boiler and another, by investigating the stress on the metal, T, on the supposition that the ends and the shell expand as a rigid whole, nor in using the equation

$$(8)\quad (2\,lt + 2\,dt_1) = l\,d\,\mathrm{P},$$

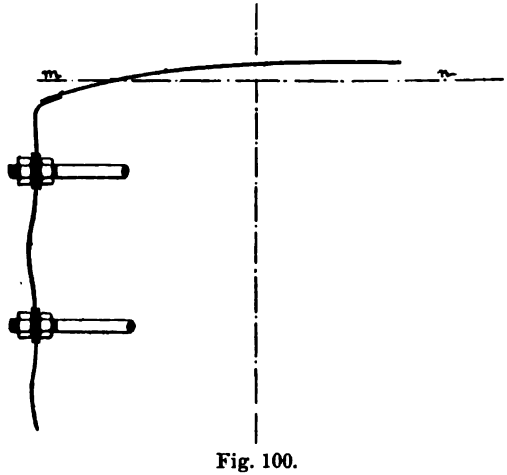

Fig. 100.

as has sometimes been done. The facts do not warrant it.

Pressure is not the only cause of strains in the shell; differences of temperature between the top and bottom are another. The hotter water naturally rises, leaving the remainder, comparatively cold, collected at the bottom, where it is further cooled by the ash-pits through which a strong current of cold air is constantly passing. The top, therefore, expands much more than the bottom, unless there is in the boiler a circulation brisk enough to thoroughly mix up the whole mass of water.

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Let *m*, *a*, *b*, *n* (Fig. 101) represent the half of a boiler on the right of the section *m*, *n*, before lighting up. The different elongations due to the temperatures at each point, if they were free to act, would give to each layer such a length that the section would become similar to *m*, *c*, *d*, *e*, *n*, but this is obviously impossible. Hot or cold the boiler must end in a plane normal to its own axis; it therefore often takes a form similar to *m*, *f*, *g*, *n*. It will be seen at once that, by this change of shape, while the central strip *h*, *i*, maintains its length, as at *h*, *k*, the outer layer *m*, *f*, becomes longer than *m*, *c*; while the innermost layer *n*, *g*, becomes shorter than *n*, *e*. The upper fibres are,

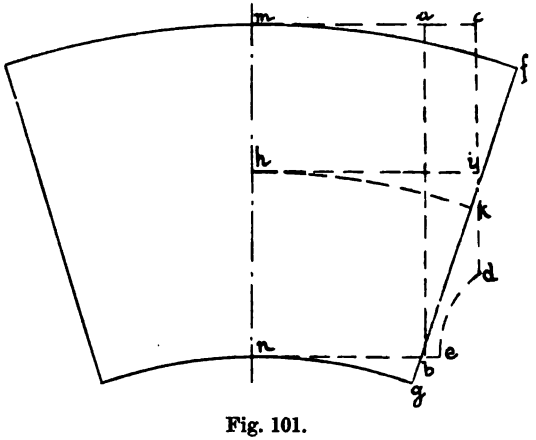

Fig. 101.

therefore, in tension, and the lower ones are in compression. On the *Surcouf*, where the difference of temperature reached 216° Fahr., it was calculated that the compression of the innermost fibres corresponded to a load of 12·7 tons to the square inch on the outside butt straps, over and above any other strains. This shows how necessary it is to thoroughly agitate and circulate the water in order to avoid these great differences of temperature; more especially in direct-tube boilers like those on the *Surcouf*.

91.—*Permanent Set and Deformation.*—While investigating the strains to which different parts of the boiler-furnace, com-

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bustion-chamber, and shell, are liable, whether by reason of unequal heating and expansion, or of steam-pressure, it has been taken for granted that, without exception, the parts were not initially strained, and were in the same condition as when under erection; in other words, it has been assumed that by former heatings the elastic limit of the metal has never been exceeded, nor its physical properties in any way altered. This is anything but the case in actual practice.

When a strip of metal, free to change its shape, is unequally heated, permanent set is produced. To take the most simple case: suppose, for instance (Fig. 102), that a strip of plate *a b c d* is highly heated on its lower portion *e f c d*, while *a b e f* remains cold; the expansion which should lengthen *d f* to $d^1 f^1$ being neutralised by the resistance of the cold part, the lower heated

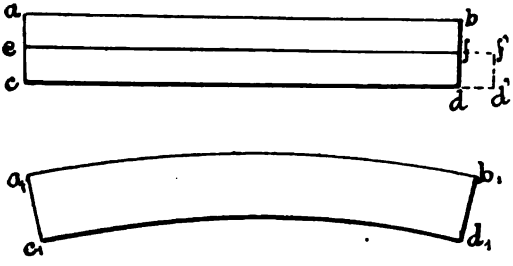

Fig. 102.

portion is compressed beyond the limit of elasticity; at the same time the upper cold portion is stretched beyond the same limit, and, in addition, is not in any way annealed. On cooling, *a b* will be longer than *c d*, and the piece of plate will take the shape a_1 b_1 c_1 d_1. Skilful boilermakers are well aware of the effects of partial heating, and make use of them sometimes to obtain, without any hammering, pieces of plate of complicated shapes.

These phenomena have been investigated by Mr. Yarrow, and M. Garnier, of the French Navy, has followed up the subject at Indret more thoroughly by experimenting on strips of iron and steel, with their ends butted against strong and rigid castings. M. Garnier made further experiments more

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nearly approaching those met with in practice, where the strips are firmly secured at either end, and are stayed in the centre like fire-boxes (Fig. 103). Finally, he experimented on discs of iron, steel, and brass plate, exposed to local heating. The results obtained agree very closely with those given by theory; they have confirmed the occurrence of permanent sets in plates free to expand, and also the phenomena known as "blistering."

The greater number of the different parts of a boiler are so put together that they cannot alter in shape; it follows that, instead of permanent sets, permanent molecular tension must be set up. These tensile strains are clearly manifested when a

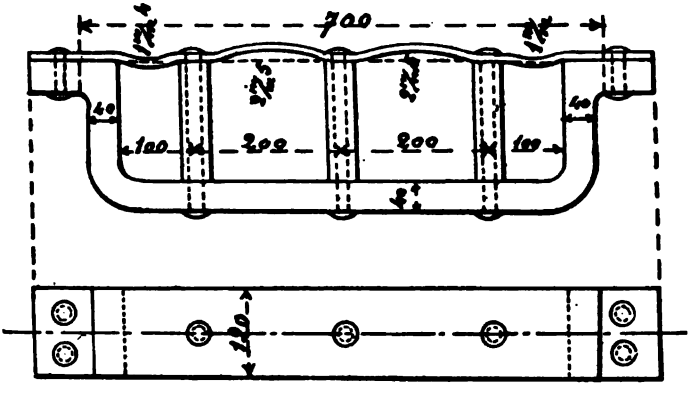

Fig. 103.

boiler is broken up. It often happens, when knocking off the heads of a row of rivets, that the last ones strip off themselves, or, at any rate, that, on taking out the rivets, the plates suddenly slide over one another, so that the holes are no longer fair. It is probable that these interior tensile strains have something to do with the accidents to which boilers are liable.

And, further, experience would appear to show that both iron and steel are deteriorated, change their molecular texture, and become very brittle by being repeatedly heated and cooled. This would account for the somewhat frequent giving out of the seam between the furnace and the combustion-chamber, a point

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where strains due to pressure are moderate, but where the local heating is excessive. This is one of the numerous deteriorations of the metal known to boilermakers as "burning." It is also to be noted that those parts most exposed to great variations of temperature are, at the same time, subject to unequal distribution of temperature, causing internal compressive and tensile strains beyond the limit of elasticity.

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CHAPTER IX.

LOCOMOTIVE BOILERS.

§ 3. APPLICATION OF LOCOMOTIVE BOILERS TO THE NAVY.

92. *Reasons for the Adoption of Locomotive Boilers.*—The preceding chapters have been principally occupied with the cylindrical boiler, which is the type at present most largely used upon warships, and is also, with few exceptions, in general use in the mercantile marine. There is, however, another form of tubular boiler, which differs materially from the ordinary cylindrical type; it is known as the *locomotive boiler.*

Two reasons have led to its introduction into the navy, namely:—

(1) *The question of weight.*—Cylindrical boilers are very heavy on account of the large volume of dead water in the lower part of the boiler, especially in boilers of the non-return or direct-tube type. In locomotive boilers, on the contrary, the furnace is only surrounded with small water-spaces, which are just sufficient to utilise the heat. For a working pressure of 130 lbs., at which locomotive boilers were first worked, their weight was about eight-elevenths of the weight of a direct-tube cylindrical boiler working at the same pressure.

(2) *Ability to stand high rates of forcing.*—Forced draught has from the very beginning been employed upon locomotives; it was therefore natural that when forced draught was introduced into the navy, the boilers which had always been associated with forced draught should be introduced at the same time.

The preceding considerations lead to the anticipation that

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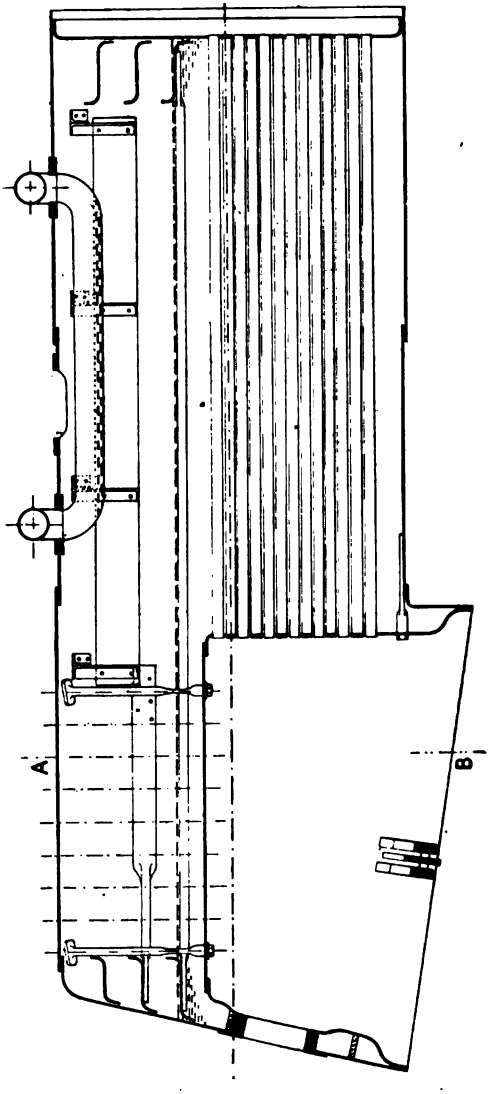
locomotive boilers would come into general use in the navy, but these expectations have not been realised, and their em-



TORPEDO-BOAT No. 60.
Locomotive Boiler (Type E).
Section on C D (Fig. 104a).

Fig. 104.

ployment has been limited to certain classes of vessels. They have only been in use on torpedo-boats, and torpedo-gunboats,

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and have now given place to the tubulous boiler, which has been substituted for them, and is entering into competition with the cylindrical boiler upon larger vessels.

93. *Description and Construction.*—As the employment of locomotive boilers has not been general, and their complete disappearance is probably only a question of time, a brief description will be sufficient, the reader being referred to works dealing with railway locomotive boilers for the details of their construction. They are distinguished by the arrangement of the furnace, the two sides and crown of which are flat unbroken surfaces; moreover, the bottom of the fire-box is entirely open to the air, the draught being due to the velocity of the train as well as to the nozzle. The furnace plates, including the tube-plate, are now of steel; the tube-plate was formerly made of red copper hardened by hand-hammering, which reduced the thickness of the plate by about $\frac{1}{16}$ inch.

Section on A B (Fig. 104).

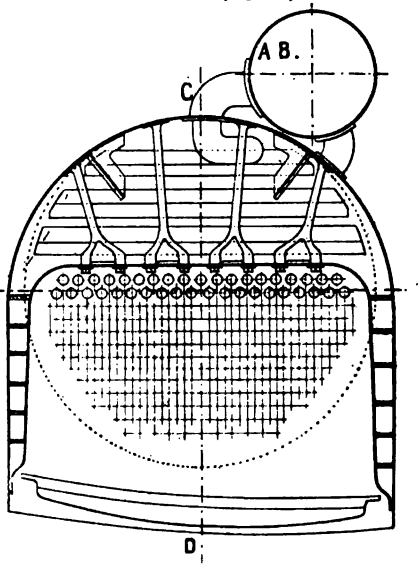

Fig. 104 A.

The fire-box being high and unobstructed acts as a combustion chamber.

The outer shell of the boiler in the neighbourhood of the furnace is composed of flat plates stayed to those of the furnace, and the top of the boiler is semicircular in shape, the furnace crown being suspended from it by stays. The rest of the boiler is circular, being the continuation of the semicircular portion above the furnace.

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The tubes are very long and of small diameter.

The marine type of locomotive boiler differs principally from the railway locomotive boiler in two points.

The small amount of headroom available necessitates the grate being placed much higher than in locomotives, and consequently nearer the entrance to the tubes, and the necessary space for thoroughly mixing the gases is consequently very much reduced.

The small amount of room available in length necessitates the employment of shorter and stiffer tubes.

Unless locomotive boilers are handled with considerable care, trouble is sure to ensue; leaky tube-joints occur at draughts much inferior to those in vogue in ordinary locomotive practice. Faults in the furnace-plates, furnace-joints and tube-plates, and corrosion in the bottoms of the flat water-spaces necessitate frequent repairs. The boilers do not last long, five years (torpedo-boat No. 16 and many others) being the usual life of this type of boiler. The boiler of torpedo-boat No. 21, however, lasted for nine years, and that of torpedo-boat No. 37 for twelve, having, during that time, been 5,000 hours under steam.

Their numerous failures have been ascribed to many causes. Mr. Marshall, for example, attributes them to the lack of circulation near the tube-plate, and proposes fitting a flat water-space under the furnace, where the water, in all probability, would remain stagnant; he has not, however, applied the remedy that he has proposed.

Figs. 105 and 106 show two arrangements adopted to prevent the hot gases reaching the tubes too quickly; in the first case, the baffle is formed by a water-space, called a "Tenbrinck" after the inventor, and in the second by a prolongation of the fire-bridge.

Setting aside any defects in design, and above all of position of the grate, the main difference between the life of a boiler on board ship and upon a locomotive depends entirely upon the difference in the nature of the service they are called upon to perform. In locomotives, the boilers are only in use for five or six consecutive hours, after which they are inspected and cleaned; they experience neither change of stokers, nor drawing

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CHISIMA, JAPANESE TORPEDO-GUNBOAT.

LOCOMOTIVE BOILER WITH TENBRINCK FIRE-BRIDGE.

Section on A B.

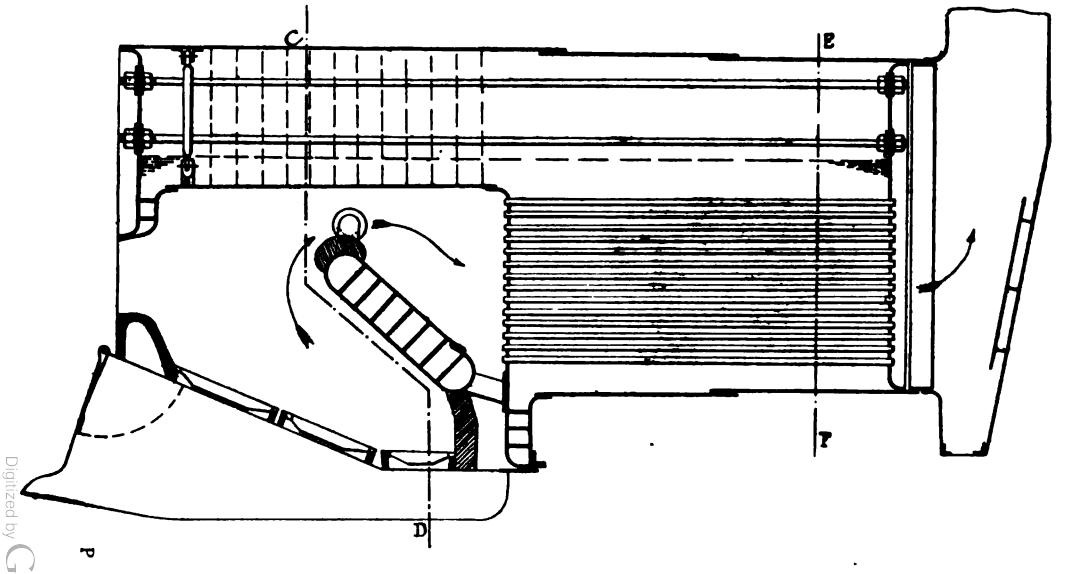

Fig. 105.

Half section on C D.

Half section on E F.

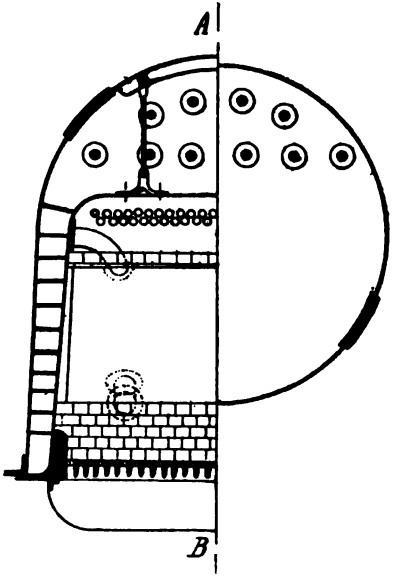

Fig. 105A.

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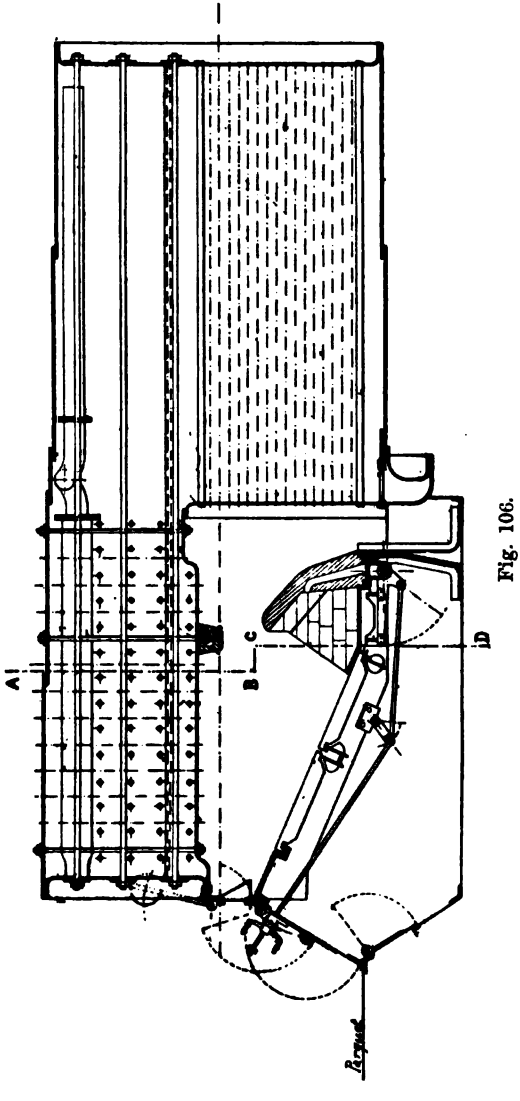
fires, nor cleaning tubes while under steam, or briefly, any of



TORPEDO-GUNBOAT, FAUCON TYPE.
MODIFIED FORM OF LOCOMOTIVE BOILER.
Section on E F (Fig. 106A.).

Fig. 106.

the severe handling which is detrimental even to the strongest and best constructed tubular boiler.

The reason that leaky tube-plates are not so prevalent on

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locomotives as on board ship is principally because the air-pressure in the furnace is nearly the same as that of the surrounding air.

The pressure in the ashpan, due to the speed of the train, overcomes, in fact, the resistance through the grate; and the draught due to the nozzle has only the resistance of the tubes to overcome. In consequence, the opening of the fire-doors on the locomotive does not give rise to the sudden inrushes of

Half front elevation. Half section on A B C D (Fig. 106).

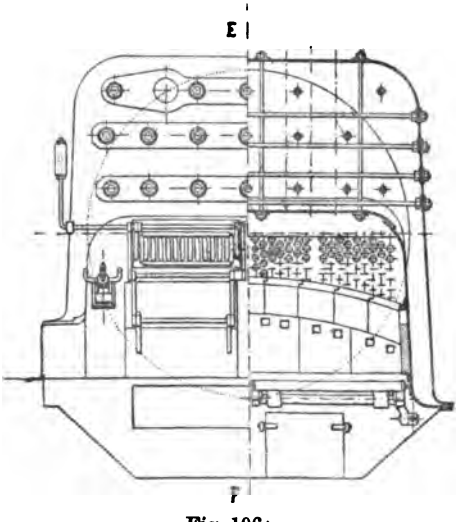

Fig. 106A.

cold air, which are so detrimental to the tube-plates of marine locomotive boilers. The resistance of the grate and tubes in these latter has to be overcome by the difference in pressure between the stokehold and funnel. Consequently, the pressure in the furnace being below that in the stokehold, due to the resistance of the grate, any opening of the fire-door must necessarily give rise to sudden inrushes of cold air.

It may also be noted that the flat furnace crowns of the locomotive boiler expose a very much larger surface liable to be overheated, should for any reason the feed be stopped, than do the crowns of cylindrical boilers. The result of this overheating of the plates is frequently the drawing of the stays,

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and consequent serious accidents to the stokers. It may be remarked that the economy in weight realised by the use of direct-tube boilers with a locomotive fire-box, might have been obtained by the use of return-tube boilers, by constructing them as a half cylinder, terminated at the bottom by a row of stayed furnaces. Rigidity could have been easily assured by means of

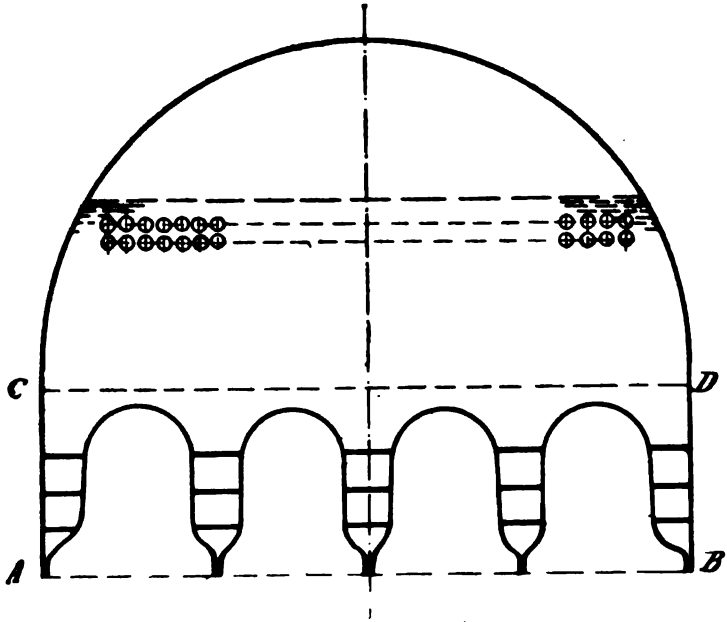

Fig. 107.

stays placed in the lower portion, either at CD, or even AB, Fig. 107.

This arrangement, which would not have exposed the furnace crowns to any danger, was advocated by M. Joessel at the time when pressures were 56 lbs. per square inch, but it has never been carried out.

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CHAPTER X.

§ 4. GENERAL REMARKS.

94. *Life of Marine Boilers.*—After the foregoing description of the various causes of failure in boilers and the precautions which must be taken to prevent them, it must be admitted that the marine type of boiler, if well constructed and handled with care, is both reliable and durable. Failure is more generally due to the result of chemical action, to which, however, all boilers are exposed, than to any mechanical strains. The most frequent sources of accidents are leaky tube-joints or seams, which give rise to corrosion. The boiler-shell sometimes shows rapid wear round the feed-water inlet, and especially at the water-level. Formerly, the iron furnace-plates were liable to blistering and other defects, which have now been overcome by the use of steel.

Local and often deep pitting is met with where the steam is produced in greatest abundance; it seems as if the steam-bubbles hollow out at this point a sort of nest or forming place, but this kind of corrosion is, however, mainly due to the action of air-bubbles. If the air-bubbles once commence to free themselves at any point, they continue to do so until the metal is deeply pitted. This corrosion is very rapid, and apparently brings about the liberation of hydrogen, and it is further assisted by the presence of carbonic acids. It is chiefly to be feared in non-homogeneous material, or where brazing or welding has taken place. It appears very little, if at all, upon steel, especially if the metal contains chromium or nickel, and it is entirely prevented by the presence in the water of borax or an alkali. When they have never been subjected to over-heating, the furnace-plates will last as long as the shell-plates.

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Iron and steel tubes often corrode at the welds, but brass tubes will outlast the rest of the boiler.

The reduction in thickness of the boiler-plate, brought about by constant wear, is extremely slow. In many liners the boilers are in very good condition after ten years' service, without having undergone any extensive repairs. Even after they have been removed from the liners, which is generally done after about twelve years' service as a precautionary measure, the same boilers have been worked on cargo boats for another five or six years.

Instances are not wanting where boilers have been in use for over twenty years. As examples may be mentioned, the boilers of the *Notre Dame du Salut* on the Madagascar station, and those of one of the White Star Company's liners which were put in in 1871 and were still in working condition in 1895.

In the navy, the intermittent nature of the service, the long periods of inaction during which they must be held in readiness to be put in commission at any moment, and the constant changes in the engine-room staff, are not conducive to the long life of a boiler. Under these conditions a boiler is not expected to last longer than eight or ten years, and will have to be thoroughly overhauled at least once during that time. There is, at least, the satisfaction of knowing that in going into commission with the ship's boilers in good condition, they will last throughout the time the vessel is on a foreign station, and, should occasion arise, the length of time in commission may be doubled without necessitating extensive repairs to the boilers while abroad.

It should be noted that the above refers to return-tube boilers alone, as boilers with straight tubes do not last as long, and locomotive boilers cannot be used for three years without repairs, their life being not more than six years at the most.

95. *Weight of Tubular Boilers.*—In getting out the total weight of a ship, under the head of weight of boilers is included everything that is concerned in their working, in the purifica-

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tion of feed-water, in the circulation of the air in forced draught, and in general, everything connected with the stokehold, including tools and spare gear. In the nomenclature of the different parts composing this total, a complete list without any omission has been aimed at, which is all that is necessary.

In a work which attempts a comparison of different types, and endeavours to show what changes of weight correspond to a change of system, a more rational method of classification must be employed. The following is most convenient.

I. *Elements varying with the working pressure* II, and whose weight per square foot of grate ought to be proportional to that pressure.

1. Body of the boiler without fire-bars or masonry.
2. Stop-, safety-, and reducing valves, separators on steam-pipe and super-heaters.
3. Piping, and cocks and valves in the stokehold.

II. *Elements depending on the rate of working*, that is to say, on the quantity of coal burnt per square foot of grate, and on the quantity of water evaporated per square foot of grate. The total of these weights per square foot of grate should be proportional to the combustion K.

4. Feed-pumps.
5. Feed-water tanks and reserve tanks.
6. Feed-water heaters.
7. Filters and purifying apparatus, lime water-tanks.
8. Distillers for "make-up" feed-water.
9. Water in feed and reserve tanks, and in the above-named fittings.
10. Fans for forced or suction draught.

III. *Elements independent of both* II *and* K which ought to be directly proportional to the grate-area G.

11. Water in boilers.
12. Grates, firebricks, and fire-bridges.
13. Funnels, uptakes, and smoke-boxes.
14. Non-conducting coverings, casings, and lagging of all kinds.
15. Tools and spare gear.
16. Stokehold floors and ladders.

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Logically, these latter should be classed with the hull.

It is very seldom in the machinery lists that any means are found of allotting correctly the total weight among these three groups—P_1 the weight varying with the pressure Π, P_2 the weight varying with K, and P_3 the weight independent or nearly so of Π and K. Most frequently, only the total weight, $P = P_1 + P_2 + P_3$, is given, the subdivisions being merely arbitrary distinctions for the purpose of simplifying the classification.

Whatever the type of a boiler may be it is characterised as far as weight is concerned by the ratio

$$\frac{P}{G} = A \tag{1}$$

the weight per square foot of grate. It is necessary, in order to ascertain its true value, to determine its relation to the water evaporated per square foot of grate, but as this is hardly ever known, it is replaced by the power developed per square foot of grate.

$$\frac{F}{G} = B \tag{2}$$

where F is the total indicated horse-power.

The power B per square foot of grate is a very complex element; it depends upon the combustion K and upon two quantities, the water evaporated per pound of coal, and the horse-power of the engine per pound of steam. Going back to the only data usually given, which refers to these two quantities, namely, the coal per horse-power hour C, we have

$$C = \frac{K}{B} \tag{3}$$

From the value of D the weight of a boiler per horse-power, we have

$$D = \frac{P}{F} = \frac{P}{G} \times \frac{G}{F} = \frac{A}{B} = \frac{AC}{K} \tag{4}$$

This weight is then proportional to the weight per square foot of grate and the consumption of coal per horse-power, and

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NAME OF SHIP.	Total Weight in Lbs.	Grate Su in Sq.	Number of Expansions in the Engines.
	P.	G.	Δ
Sfax	1,105,235	538	4·88
Manche	142,958	87	5·64
Amiral Baudin	1,391,276	763	3·32
Cécile	..	852	5·06
Isly	1,215,725	582	7·77
SS. *Bretagne*	..	810	9·05
D'Entrecasteaux	1,618,590	972	7·61
SS. *Gascogne*	2,362,866	842	9·07
Hoche	1,434,140	560	4·64
Matsou-Sima	872,538	387	5·77
Dupuy de Lôme	1,747,359	609	8·900 * / 9·217 †
Suchet	1,260,407	430	7·831
Linois	763,924	389	7·59
Torpedo-boats Nos. 105–114	28,880	24	4·67
Torpedo-boats Nos. 127–129	40,430	30	3·80
Bombe	109,909	77	3·55
Achéron	189,230	86	5·96

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inversely proportional to the weight of coal burnt per square foot of grate.

It is known that the consumption per horse-power C diminishes rapidly as the pressure rises; this is due to the efficiency of the engine which improves with the greater number of expansions possible with high pressures, but not to the direct effect of the pressure, as may be readily shown in the following manner.

The boiler can evaporate practically the same amount of water at all pressures, especially when the pressures are high; this may be seen by reference to the Table on page 44 giving the total quantity of heat Q contained in one pound of steam at varying pressures.

On the other hand, the volume of one pound of steam V is nearly inversely proportional to the pressure Π at the high pressures now in use; its value in cubic feet may be roughly calculated from the equation

$$\Pi V = 440$$

The two quantities, Q and Π V, both remaining practically constant, neither the efficiency of the boiler nor that of the engine would change when Π varied; consequently, C would remain constant if the rate of expansion was not altered.

When the rate of expansion varies, only the weight per horse-power of boilers supplying steam to similar engines can be compared. The weight A per square foot of grate expresses the lightness of a boiler for a similar consumption of coal K; their weight per horse-power D expresses their fitness to support this consumption K. The following ratio then exists between these two weights:—

$$\frac{A}{D} = \frac{K}{C}$$

in which C is assumed constant.

In grouping together similar boilers and classifying these groups according to the number of successive expansions in the engines, the following Tables are formed for the most recent types of tubular boilers:—

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In Table I. the total weight P is generally taken from the table of weights, allotting to the boilers 40 per cent. of the total weight of tools and spare gear allowed for boilers and engines; the error committed in certain cases by this has no appreciable influence upon the values of A and D.

The power F is the maximum horse-power obtained with forced draught and with a consumption of coal K. As in many cases, similar boilers, or, at least, boilers which are capable of standing the same intensity of draught, have been experimented upon at very different draughts, depending upon the consumption of steam of the engines, the figures in column A give a better means of comparison of different types than do those in column D.

Table II. gives the weight of the several component parts of a boiler classified as elements depending upon the pressure, elements depending upon the consumption of coal, and elements depending directly upon the grate-area.

96. *Space Occupied.*—Having given the weights of the various types of tubular boilers, the Table on the next page gives the space occupied.

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	LOCOMOTIVE TYPE.					
	LINOIS.	TORPEDO-BOATS 104–114.	TORPEDO-BOATS 127–129.	BOMBE.	ACHÉRON.	Line
n lb	160	133	142	121	85	1
.	389	24·8	30·4	77·5	86	2
.	14,731	1,119	1,423	3,629	3,617	3
.	6,608	518	1,015	1,944	1,668	4
.	35·84	55·6	58·63	58·85	43·05	5
l .	2·11	2·65	1·75	2·35	2·22	6
bars or r tors on	362,010	15,432	21,049	57,005	81,416	7
.	11,130	275	..	1,323	4,797	8
.	31,700	361	655	2,756	11,022	9
.	404,840	16,068	21,704	61,084	97,235	10
.	1,041	649	714·9	788·2	1,130	11
.	6·51	4·88	5·02	6·52	13·29	12
.	11,383	366	342	{On main Engines.}	4,025	13
.	Built to hull.	549	441	1,213	1,367	14
.		..	..	..	..	15
tanks	5,798	..	397	..	1,164	16
.	4,535	137	143	..	154	17
n the						
.	20,283	1,543	1,543	4,850	15,632	18
.	6,951	304	412	1,565	3,911	19
.	..	..	..	..	..	20
.	48,950	2,899	3,278	7,628	26,253	21
.	125·9	116·92	107·8	98·42	305·3	22
.	3·51	2·10	1·84	1·67	7·09	23
.	206,570	6,282	10,298	25,924	41,002	24
.	27,082	1,766	2,639	4,563	5,785	25
.	41,209	1,232	1,175	3,382	11,163	26
agging						
.	9,479	212	220	1,168	2,822	27
.	10,362	331	882	4,436	3,207	28
.	15,432	90	234	1,724	2,204	29
.	310,134	9,913	15,448	41,197	66,183	30
.	797·4	400	508·5	531·7	769·6	31
	763,924	28,880	40,430	109,909	189,671	32
$P_1 + P_2$	341·1	12·89	18·05	49·07	84·69	
$\frac{P_1 + P_2}{(\frac{1}{2}}$	1,964	1,165	1,331	1,418	2,206	33
t. of gr	17·08	20·9	33·40	25·10	19·4	34
$\frac{P_2 + P_3}{F}$	115·1	55·76	39·84	56·57	113·7	35

[*To face p.* 218.

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TABLE III.

		Name of Ship.	Horizontal projection in Square Feet— of the Boiler c.	Horizontal projection in Square Feet— of the Grate g.	Ratio $\frac{c}{g}$
Single-ended boilers.	2 furnaces	*Sfax*	102·39	42·95	2·384
			110·85	46·75	2·371
	2 „	*Manche*	92·17	43·81	2·104
	3 „	*Amiral-Baudin*	106·3	63·61	1·671
	3 „	*Isly*	150·16	73·74	2·036
			144·63	70·29	2·058
	3 „	SS. *Bretagne* (old boilers)	145·12	70·07	2·071
Double-ended boilers.	3 furnaces (combustion chamber common to all three)	*Cécile*	252·75	142·09	1·779
			250·0		1·759
	3 furnaces	*Capitaine Prat*	266·57	137·76	1·935
	4 furnaces (2 combustion chambers separated by a water-space)	*D'Entrecasteaux*	280·10	194·28	1·441
	4 furnaces (2 combustion chambers separated by a water-space)	*Columbia*	329·33	168·01	1·960
Admiralty boilers.	3 furnaces	*Hoche*	216·62	70·00	3·094
	3 „	*Matsou-Sima*	183·91	64·59	2·848
	2 „	*Dupuy de Lôme*	201·48	57·15	3·525
	2 „	*Suchet*	189·61	46·93	4·040
	2 and 3 furnaces	*Linois*	185·06	71·20	2·599
			161·52	51·99	3·107
Locomotive boilers.	1 furnace	Torpedo-boats, Nos. 105 to 114	94·81	24·76	3·830
	1 „	Torpedo-boats, Nos. 127 to 129	116·03	30·35	3·823
	1 „	*Bombe*	77·79	19·37	4·016
	1 „	*Achéron*	95·06	19·16	4·961

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PART III.

TUBULOUS BOILERS.

General Considerations.

97. *The Introduction of Tubulous Boilers into the French Navy.*—The construction of marine boilers, at least those for use in warships, is now undergoing complete transformation. The old style of boiler, with the fires and hot gases surrounded by the water and steam which in the bygone days of wooden hulls afforded valuable protection against accidental fires, has been abandoned. In the types now in use the water is surrounded by the hot gases.

The material of which the boiler is composed is no longer in compression, as was the case in the older type of boiler, the principal stresses in the new type being of a tensile character.

The boiler casing is usually of thin plate, often protected on the inside by water-tubes arranged in the form of a tube wall, and the casing plates are always covered by a non-conducting material. It is therefore the casing and not the boiler-shell which forms the outside of the boiler.

Although the difference between the two systems, one of which is gradually replacing the other, is clearly marked, a universally accepted name accurately describing them, has not yet been arrived at. The name, "Water-Tube Boiler," as opposed to "Fire-Tube Boiler," is not satisfactory, because there have been rectangular boilers with water-tubes (Martin or Cochrane Boiler).

In reality, one of the principal differences in the two types lies in the casing or shell, but it should be noted that there are several types of water-tube boilers having walls composed of

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flat plates with a water-space between them. The name "Multi-tubular Boiler" is quite unsuitable for a type which sometimes contains fewer tubes than the older type.

In contradistinction to "Tubular Boiler," the name which custom has allotted to the old cylindrical or rectangular boilers, the term "Tubulous Boiler," will generally be used, as it has at least the merit of simplicity. The name, however, is of little importance, as in reality there is little risk of confusion.

It is hardly accurate to apply the adjective "old" to tubular boilers, and "new" to tubulous boilers, as several types of tubulous boilers existed before cylindrical boilers; but whilst twenty or thirty years ago tubular boilers, on taking a cylindrical form, came into general use, the development of tubulous boilers has, on the contrary, been very slow. The increasing importance of weight, and the adoption of pressures too high for other boilers, necessitated the introduction of tubulous boilers.

In spite of their acknowledged advantages, two causes helped to retard the adoption of tubulous boilers. The first was the difficulties experienced in working, which were only surmounted by degrees, and which even at this present moment have not been entirely overcome; the second was the corrosion of the thin tubes, which always renders their durability uncertain. In this respect progress has also been made; and it should not be forgotten that the adoption of steel tubes in cylindrical boilers has diminished their early superiority. The two great objections to the tubulous boiler have, therefore, gradually lost their weight. At present, in most navies, tubulous boilers are exclusively used on torpedo-boats, and on the class of enlarged torpedo-boats now becoming more and more numerous, such as destroyers, and torpedo-gunboats. They are being extensively used on cruisers, and are beginning to be adopted on ironclads. Cylindrical boilers are still employed on a few warships intended for foreign service. Tubulous boilers are rarely met with in the merchant service. The recent extensive adoption of these boilers in the navy is principally due to the experience acquired on torpedo-boats.

The different types of tubulous boilers are of extremely

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varied construction. Some types have only been employed on land, but those only will be considered which have been adopted on board ship, dismissing in a few words all such as have not yet found their way into general use afloat. Leaving aside constructive details, the boilers are most readily classified according to the means adopted for securing the circulation of the water. Thus, in Chapter II., three different groups were mentioned, boilers with *limited circulation*, those with *free circulation*, and those having *accelerated circulation*. This classification corresponds fairly well with the order in which the boilers were invented.

Boilers with *limited circulation*, which might also be called coil boilers, are characterised by the absence of water-reservoirs. The Belleville is typical of this group.

Boilers with *free circulation* might also be called boilers with vertical reservoirs and horizontal tubes, the reservoirs being generally formed of two rectangular or flat water-spaces. The principal and best known inventors in this group, at least of the French types, are Joessel, Oriolle, D'Allest, Collet and Niclausse.

Boilers with *accelerated circulation* have, as a distinguishing characteristic, vertical tubes of various shapes connecting horizontal and generally cylindrical reservoirs. The earliest inventors were M. Sochet and Commander Du Temple. The boilers of this group, constructed by Thornycroft, Normand, Yarrow, Mosher, the Du Temple Co. and several others, of which particulars will be found further on, vary very considerably in form.

The three terms *limited*, *free* and *accelerated*, do not indicate successive and regularly increasing degrees or rates of circulation. *Free circulation* is, in fact, free to be insufficient or perfect as the case may be.

For instance, it is possible that steam may be more liable to accumulate in certain tubes of a D'Allest boiler than in those of a Belleville boiler, though the first belongs to the class with *free* and the latter to that having limited circulation.

Even in a boiler of *accelerated circulation*, there might be a few tubes in which the circulation is feeble or insufficient.

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CHAPTER XI.

BOILERS WITH LIMITED CIRCULATION OR COIL BOILERS.

98. *General Characteristics of Boilers with Limited Circulation.*—The special feature of these boilers consists in the employment of tubes rising in successive coils or folds, each one of which receives the water at its lower end, and discharges the steam at its upper end. The movement of water is thus limited to what is necessary to replace that which is evaporated, and that carried over by the steam. The steam-bubbles move through almost stagnant water, and their velocity is always low.

99. *History of the Belleville Boiler.*—The history of the Belleville boiler was for a long period practically that of the tubulous marine boiler itself.

M. Belleville, was in fact, the first to grapple with the difficult problem of the employment of tubulous boilers on board ship; and he has brought to bear remarkable perseverance and great fertility of resource to the solution of the various difficulties which confronted him at each step.

The first Belleville boilers were tried on the *Biche* in 1856; they were composed of vertical iron coils, in which the water circulated in an opposite direction to the external current of hot gases (Fig. 108).

The evaporation took place so rapidly that the last few coils, which were subjected to the direct heat of the flames, contained only steam and therefore served as super-heaters. The trials, however, did not succeed, neither did those of the *Argus* (Fig. 109) and the *Sainte Barbe* in 1861; but the personal qualities of the inventor were so much appreciated by

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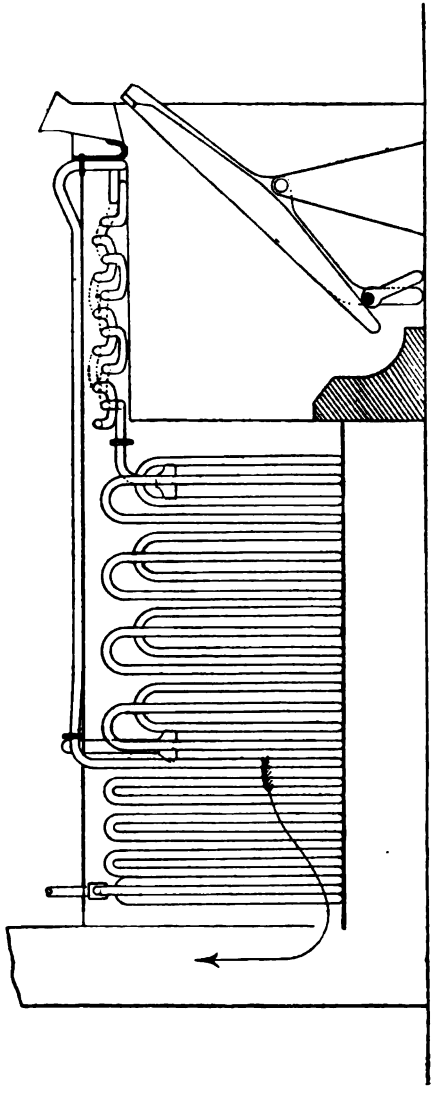
M. Mangin and M. Dupuy de Lôme that they encouraged the continuance of his experiments.



BOILER OF THE BICHE (1855 TYPE).
Scale ½.
Vertical section.

Fig. 108.

Ten years later, the Belleville boilers re-appeared with coils analogous to those of the *Argus* and composed of horizontal

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tubes, so arranged that the flames came first into contact with the tubes full of water and then ascended vertically among the remaining coils. The steam was taken from the upper part of the boiler by a transverse tube or collector, surmounted by a second tube called a "separator," which communicated with the collector by very small orifices (Figs. 110 and 110A).

This arrangement was adopted to prevent priming. The new boilers were fitted to the transport *Vienne*, the despatch boat *Actif*, a few gunboats of the *Oriflamme* type, and more particularly on steam launches which at that time were coming into general use.

BOILER OF THE ARGUS.

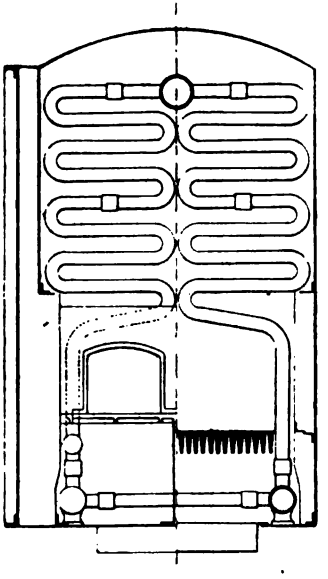

Fig. 109.

On the launches they gave such good results that the same model, somewhat modified, has been retained up to the present day; Fig. 111 shows a boiler as at present in use.

In 1869 the Belleville boiler seemed to have been sufficiently perfected, from a constructional and general service point of view, as to justify its adoption by M. Dupuy de Lôme on the yacht *Hirondelle*, a boat whose speed demanded the use of high pressures.

Figs. 112 and 113 give a transverse section of the first boilers of the *Hirondelle*, and show the feed-water collector at the bottom, and the steam collector at the top with the "separator" above it. The construction is the same as in the launch boilers, the coils being composed of horizontal tubes connected by vertical junction boxes.

The principal improvement in the *Hirondelle's* boilers was the adoption of automatic feed-regulators operated by floats such as are still being fitted to modern Belleville boilers (see

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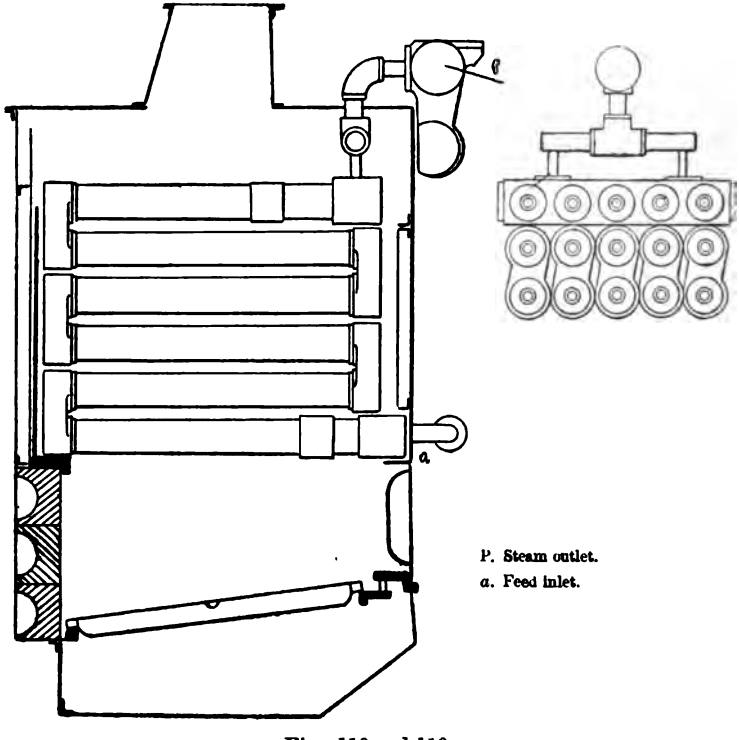
Section 175). Automatic regulation was apparently indispensable for the maintenance of a constant level in the twelve boilers which together only contained 115 cubic feet of water. A vertical separator was fitted to the steam-pipe for the purpose of trapping the water carried over by the steam.

STEAM LAUNCH (1866 TYPE). SEPARATOR.



Figs. 110 and 110A.

In the light of present experience, the 1869 boilers would not be considered adequate for the power expected on the *Hirondelle;* nevertheless, on the 21st March, 1870, a satisfactory trial was made, in which, while burning 19·9 lbs. of coal per square foot of grate, 9·3 lbs. of steam were obtained per lb. of coal as estimated from the diagrams.

The consumption of coal per horse-power was 3·8 lbs., a

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satisfactory figure with non-compound engines. Subsequently, in service, these results could not be obtained, and after a year of unsatisfactory working, it was recognised that extensive alterations to the boilers were necessary.

The sound portions of the eighteen original boilers were

STEAM LAUNCH (1895 TYPE).

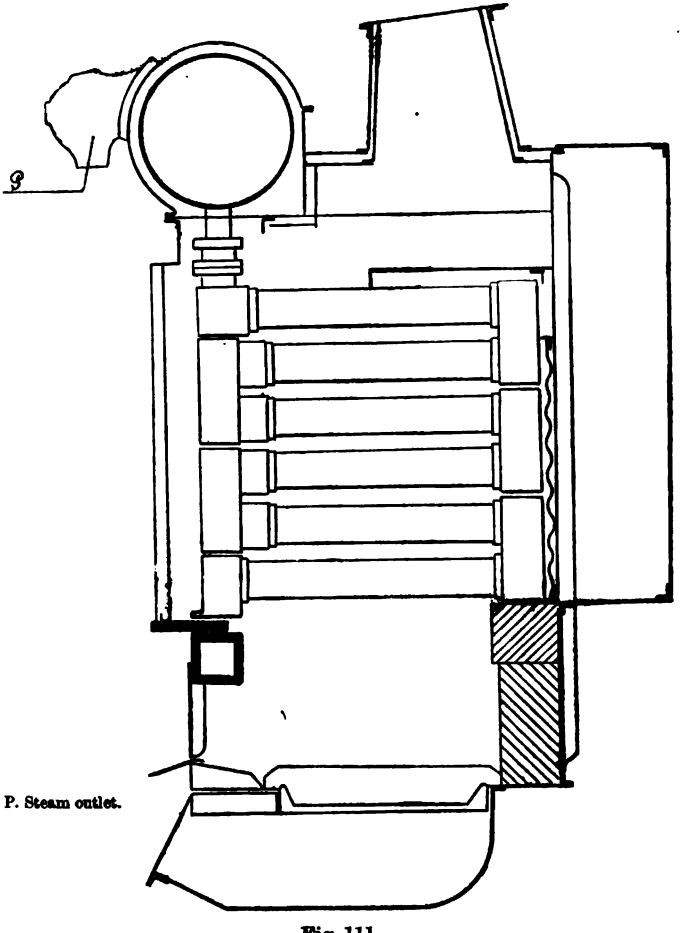

Fig. 111.

utilised in the construction of nine new ones. The second half of the set were of new design as represented in Fig. 114.

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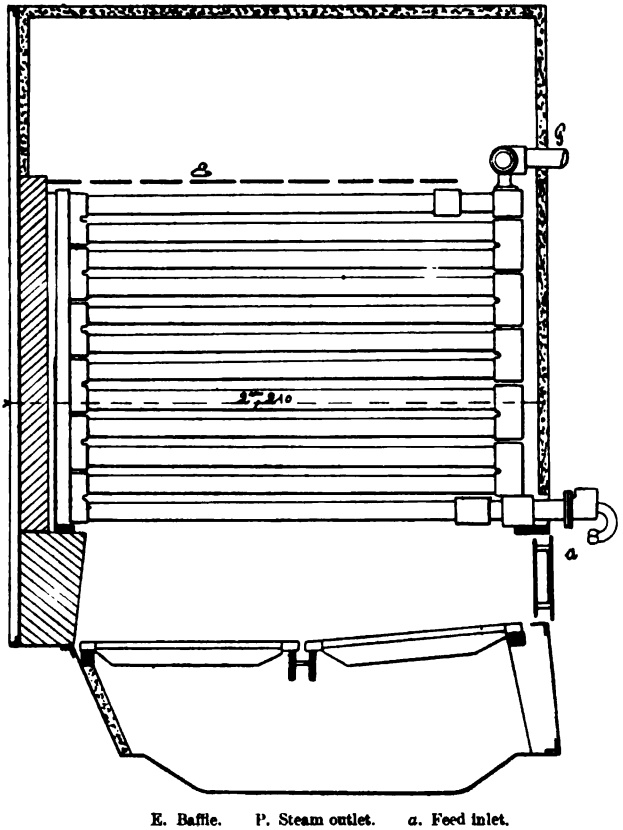
BOILER OF THE HIRONDELLE (1869).



E. Baffle. P. Steam outlet. *a*. Feed inlet.

Fig. 112.

SEPARATOR.

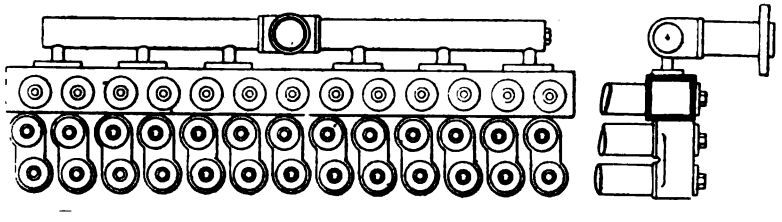


Fig. 113.

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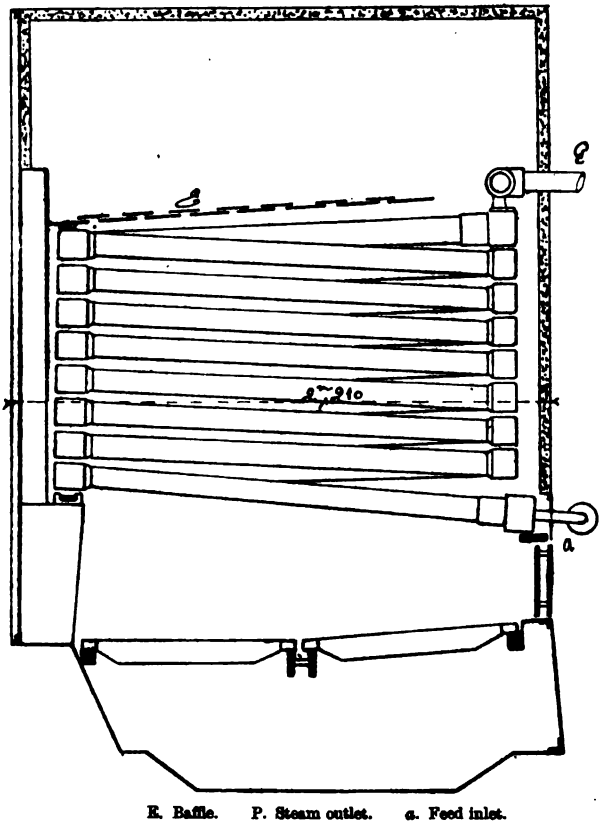
The tubes were inclined and connected by horizontal junction boxes; this arrangement facilitated the disengagement of the steam and has since been exclusively adopted. In the 1872

BOILER OF THE HIRONDELLE (1872 TYPE).



E. Baffle. P. Steam outlet. a. Feed inlet.

Fig. 114.

model the "separator" tubes were retained as being the only known means of preventing priming and regulating the output of steam. The automatic feed-regulators operated by floats were replaced by others actuated by the difference in pressure at the top and bottom of the boiler. These worked fairly well, but have not since been adopted.

The comparative trials between the two models of Belleville

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boilers in 1873 are still of interest. Difficulties were there met with which should not to-day be lost sight of when making an installation of powerful tubulous boilers.

The 1869 boilers were irregular in working, owing principally to the steam not being able to get away with sufficient freedom.

The whole of the water was at times forced up from the lower tubes, and on one occasion all the tubes in the lower rows, which were full of steam, became red hot. Further, on account of there being no steam reservoir, the slightest irregularity in working had an immediate effect on the engine-power, which oscillated between 651 and 971 horse-power. This irregularity was especially marked with thin fires; with thick fires an excessive amount of smoke was produced, 5·4 lbs. of coal were burnt per horse-power, and the funnel became red-hot.

In the boilers of the 1872 model the steam was enabled to get away with greater freedom, but other disadvantages outweighed this and the result as a whole was not satisfactory. In order to regulate the output of steam, the total section of the separator tubes was limited to 1·18 square inches per boiler. The fall in pressure was such that with a pressure of 57 lbs. per square inch in the boiler, which corresponded to the load on the safety-valves, only a pressure of 14 lbs. per square inch was obtained at the engines. When the separator tubes were made sufficiently large to reduce the difference in pressure to 14 or 18 lbs. violent priming commenced and the fires had to be slackened. Due to the irregularity of working, the production of steam per lb. of coal remained very low. After the failure on the *Hirondelle*, M. Belleville, less discouraged than ever, came to the conclusion that his 1872 model was defective only in its details, more especially in regard to the facility for the escape of steam. He retained, therefore, the same constructive arrangements, which he has since but slightly modified, and abolished the small separator-tubes, adopting instead a steam-drum or large separator. He also placed a reducing valve on the steam-pipe. This valve could be regulated at will and successfully replaced the earlier small separator tubes. A drain, or downtake pipe, was fitted to return the water from the separator back to the

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feed-collector, the water passing on its way through a settling tank where the solid deposits could accumulate. The embodiment of these alterations constituted the 1878 model. This new type was tried with success in 1880 on the *Voltigeur*, and soon became extensively used.

The principal applications of Belleville boilers as thus constructed are those in the French Navy on the *Rigault-de-Genouilly*, the *Hirondelle* (new set), the *Milan* (Fig. 14), the *Alger*, *Léger*, *Lévrier*, *Charner*, *Bruix*, *Bugeaud*, *Tréhouart*, *Brennus*, *Bouvet*, etc., etc. The English Admiralty tried them on the *Sharpshooter*, and has adopted them for the large cruisers *Powerful* and *Terrible*, and their example has been followed by the navies of other countries. Since their adoption on the *Ortégal* in 1884, all the steamers of the Messageries Maritimes, the *Sindh*, *Australien*, *Polynésien*, *Armand-Béhic*, etc., have been fitted with Belleville boilers. They have, in fact, been more fully tested in actual service than any other type of tubulous boiler, and their employment is therefore attended with less risk and uncertainty.

100. *Description of the Modern Belleville Boiler.*—The present Belleville boiler is composed of vertical rows of nine or ten parallel tubes inclined 2° or 3° from the horizontal. Two rows inclined in opposite directions, with neighbouring tubes united by horizontal junction-boxes, constitute an element. The water-level is in practice above the fifth tube, thus leaving four or five tubes full of steam. The water is distributed to the different elements by the lower feed-collector of rectangular section, placed above the fire-doors. From this collector the bottom junction-boxes take their water, through a conical nipple screwed into the upper part of the collector, the whole being held together by a bolt (Fig. 119). The mixture of water and steam emitted from the upper ends of the elements passes through short junction-boxes into the upper cylindrical reservoir. In this reservoir the water is separated from the steam. The steam stop-valve connections are fitted to this reservoir. The principle adopted in the various pieces of apparatus for separating the particles of water from a current of

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steam, and which consists in giving sharp turnings to the current in such a way that the liquid particles are deposited on the concave walls of the passages, appears to have been applied for the first time in the separators of M. Belleville. The shape of the baffles in the cylindrical reservoir, has greatly varied. The two following illustrations represent the most simple arrangement (Fig. 117), and that which was adopted in 1894 (Fig. 116). The edges of the baffles are notched.

The feed-delivery is placed in the separator amidst the steam; the water becoming thus heated immediately on its entry into the boiler. The jet, discharged at a very high pressure, falls in the form of a finely-divided spray. This arrangement was, perhaps, originally intended to produce an immediate precipitation of the salt. M. Belleville reckoned, in fact, on the possibility of being able to use sea-water, when aided by this precipitation and the use of settling tanks. On each side of the boiler a downtake, formed by a large vertical tube, connects the separator to the feed-water collector. To its lower end—forming a prolongation—is attached the mud vessel or settling tank. The grate is composed of the usual arrangement of fire-bars; the old form of Belleville grate was described in section 29 and illustrated in Figs. 25 and 25A. The hot gases ascend vertically across the rows of tubes. The direction taken by them is of great importance, and should be carefully noted. For a long time the efficiency of Belleville boilers suffered from the too early extinction of the flames, which occurred before combustion was complete; also from the too short passage of the hot gases, which arrived at the funnel before being sufficiently deprived of their heat. The length of passage of the hot gases through the clusters of tubes has been increased by arranging horizontal screens or baffle-plates amongst the tubes, as it was difficult to augment the height of the tubes above the grate. Complete combustion was ensured by means of an energetic agitation or artificial mixing of the gases. To enable the combustion to take place in a more confined space, the old Bourdon-Thierry apparatus was used, and jets of steam, or, preferably, compressed air, were blown in above the grates. Although this arrangement is of little use in boilers

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with long horizontal furnaces, it gives very satisfactory results in Belleville boilers. The boiler thus improved has become an economical boiler under natural draught. It is able to stand slight forcing, but should not be worked at higher rates of

BOILER OF THE CHARLEMAGNE.

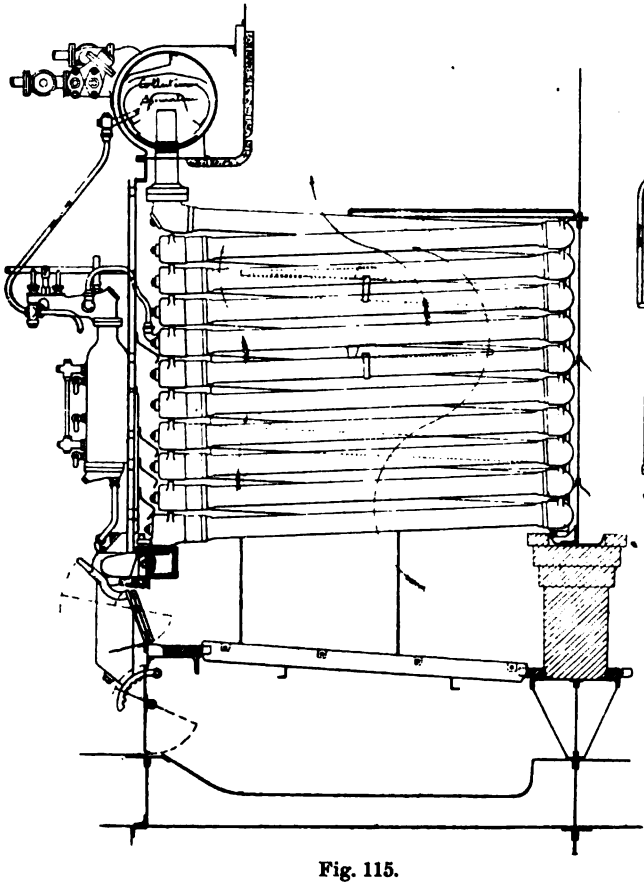

Fig. 115.

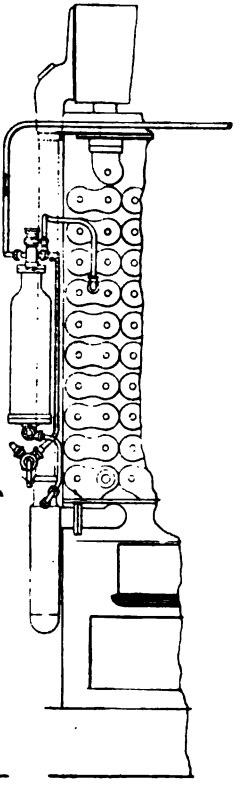

Fig. 115A.

combustion than 23 to 25 lbs. per square foot of grate, although during trial trips it has been pushed harder.

The boiler casing is made of thin double plates, the space between being filled with ashes; the boiler front is closed by doors, and the furnace is surrounded with fire-bricks.

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A new departure was made in the Belleville boiler in 1896 by the addition of a feed-water heater in the uptake. At the same time, the number of double tubes or forks in the main elements has been reduced from ten to eight. The new boiler is represented by Fig. 118. It is formed by a combination of two boilers, or rather a boiler and a feed-water heater or

BELLEVILLE STEAM SEPARATOR.

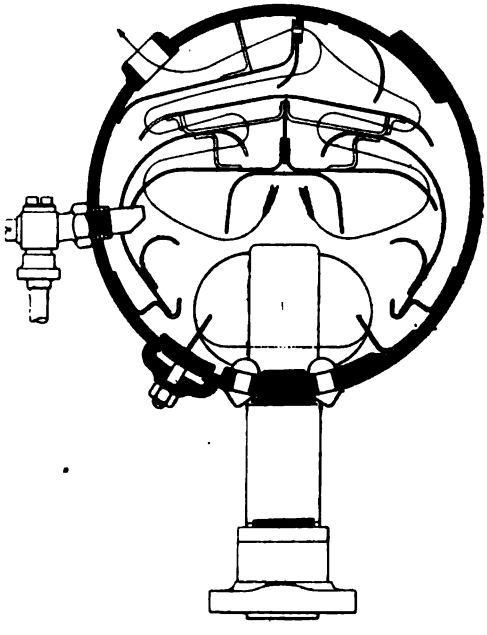

Fig. 116.

economiser, the former below, the latter above the separator. In both, the water is raised in temperature while passing from the bottom to the top. It seemed too dangerous to circulate the water in a contrary direction in the economiser.

The principal data of the first combined boiler and economiser tried were:—

	Sq. Ft.
Grate surface	43·9
Heating surface of generators . . .	1080·3
Heating surface of economisers . .	545·3

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BELLEVILLE STEAM SEPARATOR.

Longitudinal section on yz.

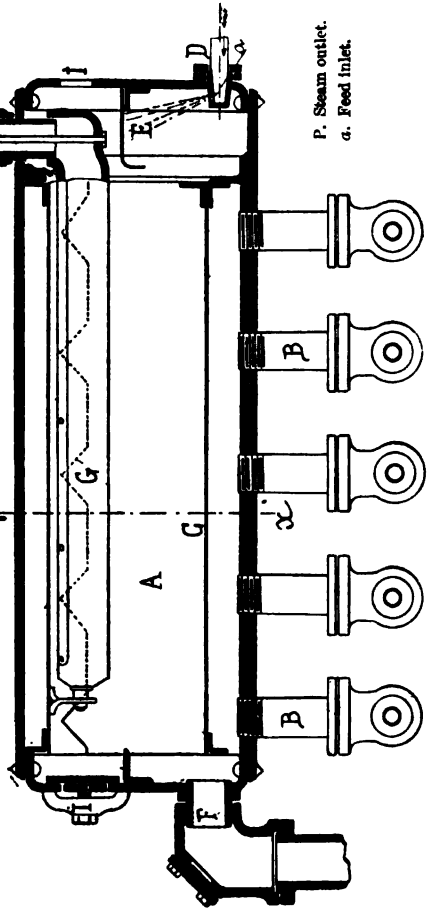

Fig. 117A.

Cross section on xz.

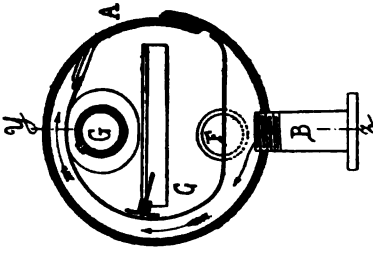

Fig. 117.

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These dimensions were modified, as shown by the data appended to Fig. 112, for the first two large boilers with eight

BELLEVILLE BOILER (1896 TYPE).

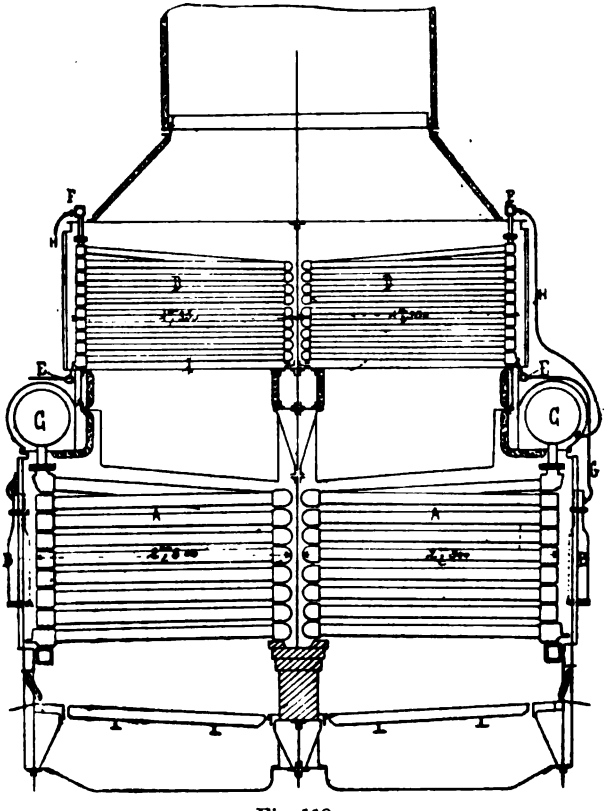

Fig. 118.

A. Generating tubes.
B. Feed-water regulator.
C. Steam and water separator.
D. Feed-water heaters.
E. Cold water collector for feed-water heater.
F. Hot water collector for feed-water heater.
G. Water-pipe from the feed-regulator B to the feed-water heater D.
H. Feed-pipe from the feed-water heater D to the separator C.

	Sq. Ft.
Grate surface (eight boilers)	419·6
Heating surface (eight boilers)	10,300
,, ,, (eight feed-water heaters)	4,053
Total heating surface	14,353
Ratio of heating to grate surface	34·2

generator elements which were intended for two boats belonging to the Messageries Maritimes. The first results obtained from

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the trials made on shore in 1896 with natural draught, were satisfactory, showing an economy in coal of 20 to 22 per cent. over the old form of boiler with ten generator elements and without economisers.

For its application in the English Navy, on board the new cruisers and ironclads, a further advance in the heating of the feed-water has been made by adding another element to the economiser and suppressing one in the boiler itself, which has reduced the ratio of the heating surface of the boiler to that of the economiser from 2·47 to 1·77. The principal data for an installation of eight boilers built to this design are as follows :—

	Sq. Ft.
Grate surface	419·4
Heating surface for eight boilers . .	8,515
Heating surface of eight economisers .	4,802
Total heating surface . . .	13,317
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	31·7

Four evaporation tests under natural draught and under forced draught, produced by means of steam-jets in the funnel, were made at St. Denis in April, 1897, on one of these boilers. The results were as follows :—

Duration of trials . . hours	8	8	4	4
Draught at the base of the funnel inches of water	0·46	0·61	0·75	1·10
Rise in temperature of water in economiser . . .	155°	176°	227°	257°
Temperature of gases on leaving the boiler . . .	842°	1067°	1256°	1528°
Temperature of gases on leaving the economiser . .	428°	554°	671°	779°
Percentage of carbon monoxide in the smoke . . per cent.	0·6	0·5	0·3	0·0
Combustion per square foot of grate . . . . lbs.	18·32	24·6	30·72	38·66
Water evaporated per lb. of coal lbs.	9·94	9·62	9·33	9·17
Steam pressure . lbs. per sq. inch	206	219	223	232

Good quality Cardiff coal was used on these tests. These results are particularly remarkable on account of the constancy

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of the combustion efficiency when the draught was increased; the observations made during the experiments throw considerable light on this subject. The great fault of the Belleville boiler lay formerly in the lowness of the combustion chamber, and the shortness of the passage of the hot gases which gave a low efficiency and bad utilization of heat as soon as the fires were at all pushed. The improvement in the utilization of heat due to the presence of the economiser was easy to foresee; besides which there was a great advance in the efficiency of combustion, as the gases re-ignited and burnt after being stirred while traversing the boiler; this is shown by the small proportion of carbon monoxide in the waste gases. Additional air-inlets are provided between the boiler and economiser in order to ensure this. It will be easily comprehended that the results thus obtained are at least equal to those realised in the old return-tube type of boiler in which the gases were well mixed by their reversal at the end of the furnace.

The Belleville boiler, fitted with the economiser, is shortly to be tried on a French battleship, and has been fitted on the *Diadem* with satisfactory results. Sir John Durston gives the following particulars of these boilers. They are thirty in number, twenty of them containing eight generator elements and six economiser elements, six with seven generator elements and six economiser elements, and four with nine generator elements and seven economiser elements. The tubes of the generator elements are of four and a half inches diameter, and those of the economiser elements of two and a half inches diameter. The following are the principal data for a boiler having eight generator and six economiser elements:—

	Sq. Ft.
Grate area	49
Heating surface of eight generator elements .	995
„ „ „ six economiser „ . .	355
Total heating surface . . .	1,350
Ratio $\frac{\text{H.S.}}{\text{G.S.}}$	27·5

The heating surface of the generator portion of the *Diadem's* boilers amounted to 29,600 square feet, and that of the econo-

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misers was 10,950 square feet, making a total heating surface of 40,550 square feet. On the full speed trial with open stokeholds, these boilers developed 17,262 I.H.P., with a coal consumption of 20·8 lbs. per square foot of grate.

101. *Details of Construction.*—Successive improvements, introduced during a period of more than forty years, have made the Belleville boiler remarkable for its excellence of construction. All its parts can be erected in place with great facility, thus avoiding the necessity for large hatchways, so often difficult to provide. The replacing of an element, in which a tube has given way, can be accomplished in two hours. The replacing of the damaged tube, when complete duplicate elements are not to hand, can be done in four or five hours. The junction boxes, which are now made of cast steel, are particularly worthy of attention. They are screwed to a slightly different thread than that on the tube ends, thus assuring a tight bearing.

JOINT BETWEEN AN ELEMENT AND THE FEED-WATER COLLECTOR.

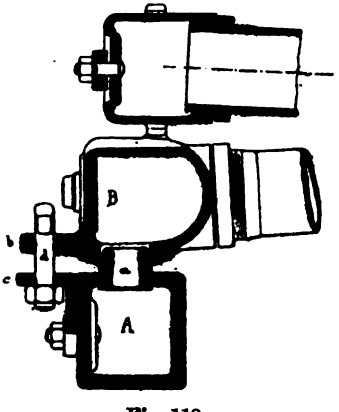

Fig. 119.

The joint is completed by a back nut, red lead being applied before tightening up. The difference between the time necessary to replace an element and that occupied by the changing of a tube in an element, is due to the fact that the back nuts can seldom be unscrewed after being some little time in service; they must, therefore, be cut with a chisel, and the tubes themselves cannot always be unscrewed from the junction boxes.

The boxes are supported, one upon the other, by small legs. The tubes are simply kept in place by their weight, and are therefore free to expand and contract.

The tubes are from $3\frac{1}{4}$ to $4\frac{1}{2}$ in. external diameter in the boilers of warships, and 5 in. in the merchant service. Their

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distance apart horizontally is 1 in., and vertically $1\frac{3}{16}$ in., for tubes of $3\frac{1}{4}$ in., and $1\frac{3}{16}$ and 2 in. respectively for tubes of $4\frac{1}{2}$ and 5 in. Their thickness is $\frac{3}{8}$ in. full for the two or three lower horizontal rows, and $\frac{3}{16}$ full or $\frac{1}{4}$ bare in., for all the others. These particulars are, however, somewhat varied in different boilers. The adoption of weldless steel tubes, drawn hot and finished off cold, has resulted in important advantages as regards durability and maintenance. In spite of the precaution taken, of introducing a little lime into the feed-water, the tubes were formerly very liable to local pitting, and sometimes opened out at the weld when overheated.

102. *General Features and Durability of Belleville Boilers.*—One of the best features of Belleville boilers is their ability to stand rough usage without danger of accident. They have nothing to fear from unequal expansion. Fires can be lit and steam got up rapidly; the rate of working can be suddenly changed, and fires can be drawn without necessitating any careful nursing of the boiler.

The curvature of the tubes in the lower rows (at times very marked), which occurs after prolonged service, does not endanger the tube connections. The tubes can withstand an internal pressure of 853 lbs. per square inch, and the separators a pressure of 284 lbs., without stressing the material beyond 3·8 or 4·4 tons per square inch. To-day several types of tubulous boilers possess similar advantages; but the Belleville boiler has had the monopoly of them for a considerable time. Their inventor first put these boilers forward as inexplosible, especially for service on land, where weight and space need not be considered. Their security against explosion should not, however, exclude ordinary care in working. Leakage of steam from a tube merely pitted through might prove dangerous, and has, at times, inflicted serious burns on the stokers when opening the boiler front doors.

The Belleville boiler is the only type of tubulous boiler which has been long enough in service to allow of an estimate being arrived at with regard to its durability. It should, however, be recognised that no fixed figure can be given as to its durability, because the different parts of the boiler wear very unequally.

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As it is very easy to replace any part that may be damaged, defects may be rectified piecemeal as they occur. It is on this account that, after sixteen years' service, the *Voltigeur* still possesses its original boilers.

103. *Weight and Space Occupied.*—As now made, Belleville boilers, for large ships, weigh, complete with water and mountings, 0·535 ton per square foot of grate. This figure is somewhat increased for the older models, such as the *Alger*, and reduced for the later ones, such as the *Pothuau*, which came out at 34½ tons (11 per cent.) below the estimated weight. The latest boilers, without economisers, constructed for the *Charlemagne*, *Gaulois*, and *Saint Louis* only weigh 0·489 ton per square foot of grate. The new boilers of the *Hoche*, fitted with economisers, should weigh 0·502 ton. The divisions or headings adopted for cylindrical boilers (elements whose weight varies with the pressure, those which vary with the rate of working, and those whose weight varies simply with the size of the boiler, as represented by the grate-area) are not exactly applicable to tubulous boilers. The tubes subjected to an internal pressure, and which in a great measure compose the first division of the Table, would in no wise necessitate an increase of weight, if required to support double or treble the pressure at which they are worked. This remark is especially applicable to the Belleville boiler, as it comprises only one single reservoir of little importance, all the other parts subjected to pressure being formed of tubes. However that may be, in order to have numbers corresponding to those given for cylindrical boilers, the same division has been retained in the Tables of Section 160, where the weights of the different elements of the Belleville boilers are given.

104. *Special Advantages of a Limited Circulation.*—Before leaving the subject of boilers of limited circulation, it is important to observe that in them the direction of the current of water, as well as its intensity, can be regulated at will. As a consequence it is possible to cause the water to travel in a contrary direction to the flame, and thus to place the coldest

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part of the boiler in contact with the cooler gases. The hot gases can, therefore, be more completely deprived of their heat than is the case in tubulous boilers of other systems.

This important property seems to have been taken into consideration at the outset by M. Belleville, and to have inspired the arrangement of his first boiler represented by Fig. 108. It was utilised later on by Mr. Herreshoff in his spiral coil boiler, where the feed-water entered at the top near the base of the funnel.

The latest models of Belleville boilers with economisers take partial advantage of this peculiarity.

The petroleum-fired boiler, of Commander Renard, has also a limited circulation, and in it the gases of combustion might theoretically be cooled down to the temperature of the feed. This last boiler, of extraordinary lightness, is intended for aerial navigation, and therefore does not properly come within the scope of this treatise.

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CHAPTER XII.

BOILERS WITH FREE CIRCULATION.

105. *Early Types with Free Circulation—Principles Embodied—M. Joessel's Work.*—The difficulties experienced when attempting to overcome the irregularity in working of the first Belleville boilers, led to the introduction of various arrangements with a view to overcoming them. The principal defects of the Belleville boiler were the insufficiency of the water circulation, which allowed steam to collect in the lower rows of tubes, and the excessive priming, due in a great measure to the absence of a steam-chamber, which rendered the engine-speed extremely irregular.

The typical "free circulation" boiler may be described as consisting of inclined generating tubes connecting two flat vertical water-spaces, the whole having the appearance of a Martin-Cochrane boiler reversed. The boiler is surmounted by a steam-drum, in which is maintained the working level of the water.

A boiler of this type was constructed at Indret, in 1869, by M. Joessel, a well-known French engineer, who, in 1862, had commenced experiments on the effects of heating the feed-water and of superheating the steam. His boiler of 1869 was of curious construction, the large upper reservoir forming quite a boiler in itself, and the water-tubes presented the peculiarity that they contained concentric smoke-tubes which ran the entire length of the boiler, and so offered a double heating surface. The furnace gases rising around the generating tubes passed through short stay tubes in one of the flat water-spaces into a smoke-box on the outside, from whence they returned by the smoke-tubes to another smoke-box at the opposite end of

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the boiler outside the second flat water-space, in a similar manner to the gases in the boiler described in Section 122. Thus, as often happens, the first boiler of the type was very

SHOP BOILER SIMILAR TO THAT OF TUG PISTON.

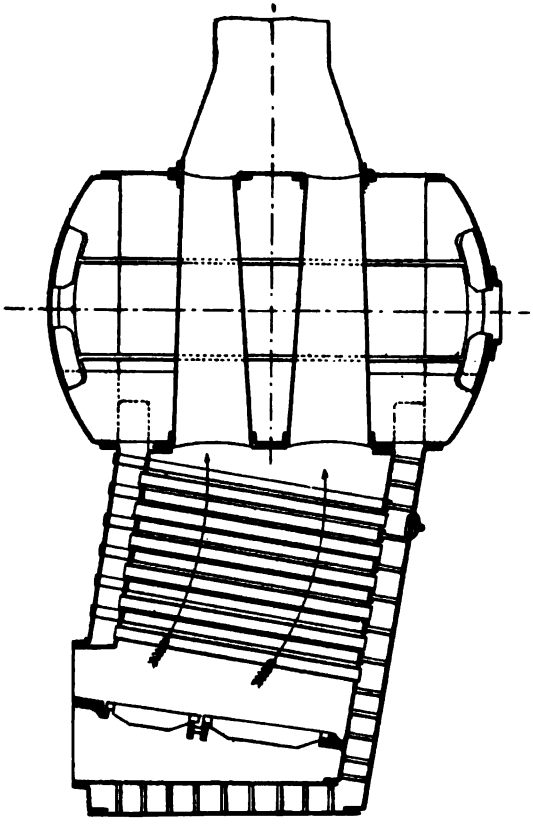

Fig. 120.

complicated in design; yet it worked for a long time on a steam-launch between Indret and Nantes.

M. Joessel, continuing his experiments, soon simplified the boiler by abandoning the internal smoke-tubes. A boiler on this design was proposed in September, 1871, but rejected; another for the tug *Piston* was approved in 1874, and the

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following year, this same type was adopted for the despatch-boats *Actif* and *Argus*. All these boilers were in active service, and worked satisfactorily. Fig. 120 represents one of a battery of land-boilers constructed in 1875. One of them was repaired in 1888 and placed on board a launch, and is probably still in service. The flat plates of the water-spaces were strongly stayed together, and hand-holes were provided opposite the ends of each tube for the purpose of inserting and expanding the tubes, and for cleaning and inspection.

The steam-chamber was of very large capacity, and had, passing vertically through it, large tubes, by which the hot gases rose to the chimney. The back water-space was continued forward underneath the fire-bars in a horizontal direction, and formed the bottom of the ashpan, thus complicating the construction without any corresponding increase in efficiency.

As the practical difficulties of construction and management appeared to have been overcome, it was decided to ask the inventor for a design for the boilers of the *Colbert*, then in course of construction, but he was of opinion that his boiler was not yet perfected, and therefore discouraged this proposed important application. M. Joessel was, in particular, dissatisfied with the premature cooling of the flames which (as in the Belleville boilers) was due to the insufficient height of the tubes above the grate.

He considered the provision of a combustion chamber between the grate and the tubes indispensable, but he never succeeded in putting this idea into practice. His experience in the working of boilers led him to realise the nature and importance of the difficulties to be overcome. As M. Joessel never patented his inventions—a great loss to marine engineering—it is rather difficult, after twenty years, to ascertain the exact part he played in the invention and development of tubulous boilers with flat water-spaces; it is, however, well known that he did play for several years a most important part in the development of this type of boiler.

106. *Penelle Boiler.*—This boiler, introduced in the steam pinnaces of the French Navy towards 1874, is a Joessel boiler

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in which the flat plates opposite the tube ends are replaced by others of spherical form. The upper part of these dished plates forms the ends of the steam-drum, the barrel of which is connected to the two inside tube-plates.

The absence of man-holes for the replacing, cleaning and inspection of the tubes, was a source of difficulty. The Penelle boiler, after being in service for several years, has been abandoned.

107. *Oriolle Boiler.*—Amongst the various types of different water-tube boilers now in service, the Oriolle boiler most nearly approaches one of M. Joessel's early designs, more especially intended for torpedo-boats. It has been adopted with success on the steam-boats of the Loire, where, to prevent smoke, coke is exclusively used as fuel. The use of fuel giving a very short flame effectively overcomes the difficulty caused by the insufficient height of the combustion chamber. The Oriolle boiler, the application of which has been very limited, may well be described before considering other types with free circulation, of which several were introduced contemporaneously with those of Joessel in 1870–1872.

In the Oriolle boiler, the flame passes immediately in among the lower tubes, which are 2 ft. 3½ in. above the grate; two vertical rows of tubes are arranged at each side so as to form the sides of the furnace.

Combustion, with a good air-pressure on board some of the torpedo-boats, was sufficiently active to enable 61·4 lbs. of coal to be burnt per square foot of grate, but, as feared by M. Joessel, the production of smoke was then so excessive, as to betray the presence of the torpedo-boats from afar. M. Oriolle has attempted, without success, to get rid of the smoke by washing the gases in a kind of water-injector placed in the base of the funnel.

The water-level is in the tubes; with a total of twenty rows of tubes, the four or five upper ones are entirely full of steam, and the three or four immediately below are, on account of their inclination, partly filled with steam and partly with water. A steam-drum is placed above the back water-space,

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sometimes parallel with the boiler front, and away from the hot gases, as on the *Lansquenet*, and sometimes perpendicularly, as on the torpedo-boats 75 to 81, 83 to 86, and 161 to 163 (Fig. 121), but always without communicating with the front water-space.

On the *Lansquenet* the tubes are of small size—1·6 in. internal diameter and 0·08 in. thick; this rendered possible a

ORIOLLE BOILER (TORPEDO-BOATS, 161 TO 163).

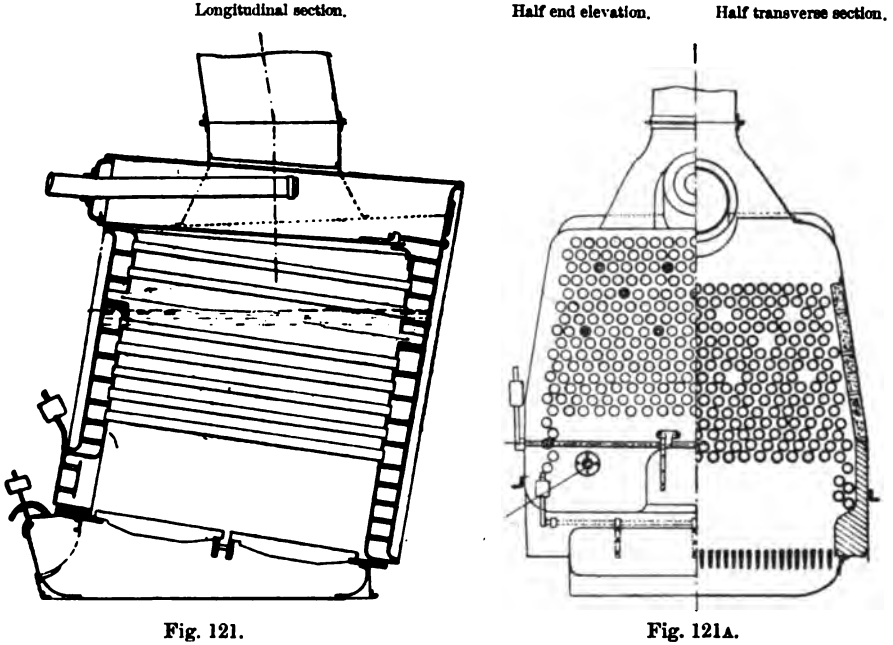

Fig. 121. Fig. 121A.

Tubes marked thus ◎ are suppressed to facilitate cleaning.

tube-surface thirty-nine times the grate-area, and a total heating surface about forty-three times that area.

The tubes were first simply expanded into the tube-plates; but latterly the Caraman joint has been used (Section 85, Fig. 78). There are no hand-holes opposite the tubes, and therefore the replacing of a tube necessitates the taking apart, or rather, the demolition of, the water-chambers. The flat plates of the water-space are stayed; some of the stays are

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formed of tubes, so as to allow of the insertion of the steam-jets used for freeing the generating tubes from soot. These tubular stays involve the omission of about one tube in twelve.

The first Oriolle boilers were fitted, towards 1890, in the torpedo-boats 75, 80, 81, 83, 84, and completed three years' service without requiring any repairs. In 1893, nearly the whole of the steam-tubes required replacing, but the water-tubes were still in good condition. The steam-tubes had to be condemned on account of the pitting occurring beneath a deposit resulting from the introduction of sea-water as "make-up," which sometimes culminated in perforations. M. Haas took the opportunity thus presented of making the investigations described in Section 76, on the formation of hydrochloric acid. Oriolle boilers have been recently fitted to the *Zouave*, the *Turco*, the *Doudart-de-Lagrée*, and the torpedo-boats 161, 162, 163. The efficiency of the Oriolle boiler was best shown during the speed-trials of these last torpedo-boats. The boilers have 48·4 square feet of grate-area, and the speed obtained slightly exceeded twenty-one knots, while burning about 61·4 lbs. of coal per square foot of grate. The power developed was not ascertained, but it can be deduced from the particulars known, supposing the power proportional to the cube of the speed; the following Table is thus obtained:—

Number of Torpedo-boat . . .	161	162	163
Coal burnt per square foot of grate per hour	62·19	58·11	62·60
Corresponding total—			
Horse-power	1,132	1,234	1,082
Coal per horse-power-hour . . .	2·66	2·28	2·88

The boilers of the *Lansquenet* have not yet been tried owing to accidents to the engines, which had nothing to do with the type of boiler.

The Oriolle boiler is remarkably light, the total weight—water and fittings included—is, according to M. de Maupeou, only 0·256 ton per square foot of grate.

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MM. Brosse and Fouché have patented a boiler which, in many respects, resembles the Oriolle boiler; the water-level is in the tubes, but much nearer the steam-chamber, and the tubes are divided into two parts, the lower ones being 2·16 in. outside diameter, and the upper ones 1·77 in.

An angle-iron baffle, placed in the front water-space, causes the steam from the lower rows of tubes to pass towards the outside, so as not to obstruct the free exit of steam from the upper rows. A similar baffle is placed in the back water-space. Another departure from the Oriolle boiler is the direct passage of the steam from the front water-space into the top drum, and the return of the water into the back water-space by large tubes, analogous to the downtakes of the Du Temple type of boiler.

108. *D'Allest Boiler.—Successive Types.*—Tubulous boilers, with flat water-spaces, are, at present, principally represented in the French navy by the D'Allest boiler. This boiler was introduced about the same time as that of M. Joessel, and, as now made, embodies the improvements patented in France by MM. Barret and Lagrafel in 1870–71, and Lagràfel and D'Allest in 1888. From the first these boilers were of similar construction to the present D'Allest boiler, except as affecting the direction of the hot gases. In the first model, the gases passed once backwards and forwards amongst the tubes, a brick baffle being arranged for this purpose at about one-third the height of the nest of tubes (Fig. 122).

In 1871 the horizontal baffle was replaced by a vertical one of bricks, extending above the fire-bridge, which caused the gases to take an up-and-down direction (Fig. 123).

Subsequently, in 1872, the horizontal baffles were again adopted, two, however, being used—one immediately above the fire, the other arranged about two-thirds up the tube-plate, as shown in Fig. 124.

This latter arrangement secured a better combustion of the coal at the back of the grates.

In all these arrangements of baffles, the utilization of the heat had in general received much more attention than the question

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of securing a perfect combustion. The boiler patented in 1888, and which we have principally to consider, is, on the contrary,

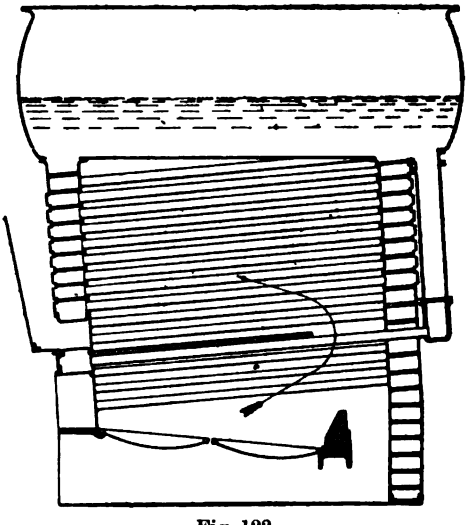

Fig. 122.

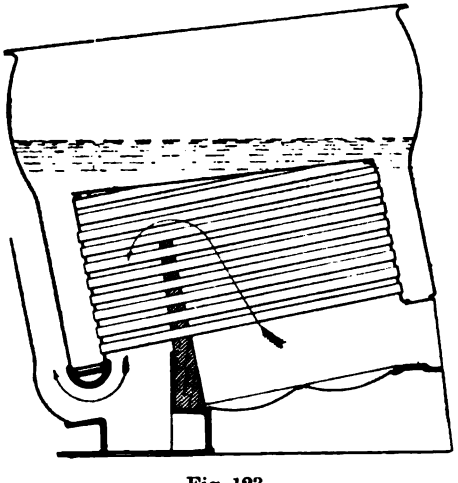

Fig. 123.

so arranged as to secure a good combustion. This is obtained by the use of a large combustion chamber, where the flames are

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thoroughly mixed prior to their entering in amongst the tubes. Barret and Lagrafel boilers were fitted in 1871 on the *Isère*, in 1873 on the *Blidah* and the *Médéah*, and later on the *Paoli*, the *Spahi*, the *Colon*, the *Kabyle*, and other steamers of the Compagnie Fraissinet. The D'Allest model of 1888 made its appearance in 1891 on the *Liban* and the *Don-Pedro*. As a result of the trials of these steamers it has been largely adopted in the French Navy. It is the only model which we shall consider at length, and is met with on the *Bombe*, the *d'Iberville*, the *Bouvines*, the *Jemmapes*, the *Jauréguiberry*, the *Carnot*, the

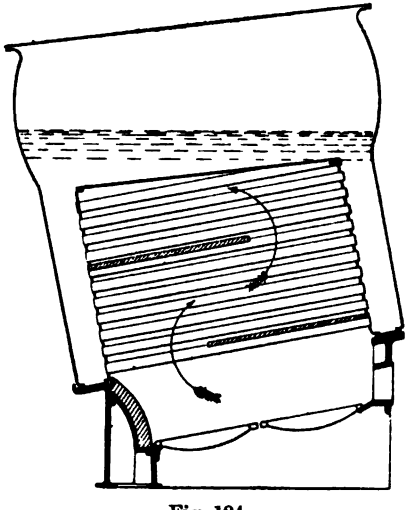

Fig. 124.

Charles-Martel, the *Masséna*, the *Foudre*, the *Chasseloup-Laubat*, the *d'Assas*, the *Cassini*, the *Casabianca*, and the *Guichen*.

109. *General Arrangement.—Space Occupied.*—The flat water spaces and the generating tubes which unite them are slightly inclined backwards so as to cause the steam to be directed towards the front. The patent anticipates the use of curved tubes, with the ends normal to the vertical tube-plates; but this construction, designed to permit the free expansion of the tubes, has not been applied in practice. Above the generating tubes is a large cylindrical reservoir connecting the two flat

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GUICHEN.

LAGRAFEL AND D'ALLEST BOILERS.

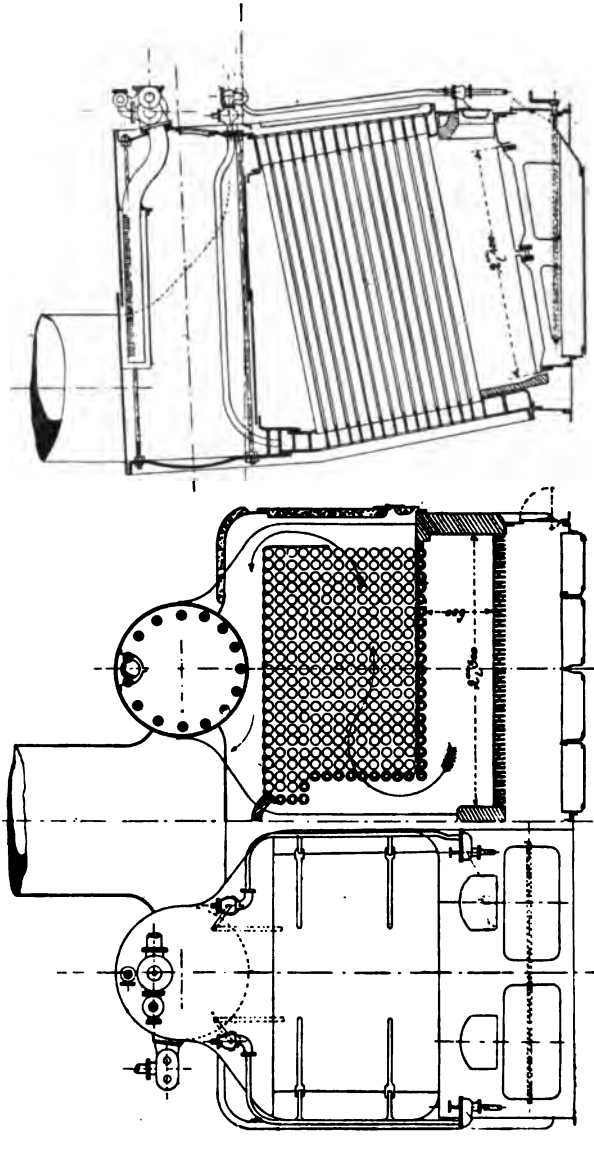

Fig. 125.

Fig. 125a.

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water spaces. The working level is in this reservoir, which serves principally as a steam chamber and separator.

The fire-box or combustion chamber which constitutes the characteristic feature of the D'Allest model of 1888, is situated at the side of the grate. A baffle of bricks resting on the bottom row of tubes directs the flame into the combustion chamber, from whence it returns across the generating tubes, taking about the same direction as in a cylindrical return tube boiler. The opening for the escape of the hot gases is placed among the lower rows of tubes and leads into a smoke-box at the side of the boiler opposite to the combustion chamber. The space occupied by the tubes and the combustion chamber is closed at the top by a second baffle resting on the highest row of tubes. Below this upper baffle there are a few rows of tubes in the combustion chamber so as to prevent it extending upwards to the top of the nest of tubes.

The direction given to the hot gases, although conducive to high efficiency, introduces a conspicuous element of danger the gravity of which has been proved by the series of accidents that have occurred—on the *Liban* in 1890, on the *Don-Pedro*, and finally, on the *Jauréguiberry* in 1896. The hottest portion of the furnace gases comes directly into contact with the upper tubes, which are never so effectively cooled by the circulation as the lower ones, and are liable to be filled with accumulations of steam, or even to run short of water, as a result of an accidental lowering of the water level. Since the accident on the *Liban*, the necessity of reducing the height of the combustion chamber has been recognised, and the four upper rows of tubes are now carried across it instead of two rows as previously (Figs. 126 and 127).

Each boiler is double, having two furnaces, two sets of tubes, two steam drums and one combustion chamber in the centre common to both furnaces.

Owing to the great length of this combustion chamber, equal to the length of the grates, its transverse width may be small and directly proportional to the width of the grate. The arrangement of the furnace and combustion chamber has of late been somewhat varied, as shown by the two figures 126 and 127,

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the first representing the boilers of the *Bombe*, the second those of the *d'Iberville*. At first greater attention was given to directing and mixing the current of hot gases; but subsequent efforts have been principally directed to a reduction in the floor space occupied. On the *Bombe* the space occupied is 2·06 times the grate area, and on the *d'Iberville* it is 1·48 times, this latter figure being even lower than for the Belleville boiler. The height of the D'Allest boilers is about 12 ft. 9½ ins. for those

BOMBE.

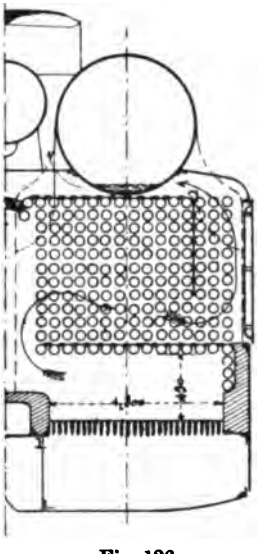

Fig. 126.

D'IBERVILLE.

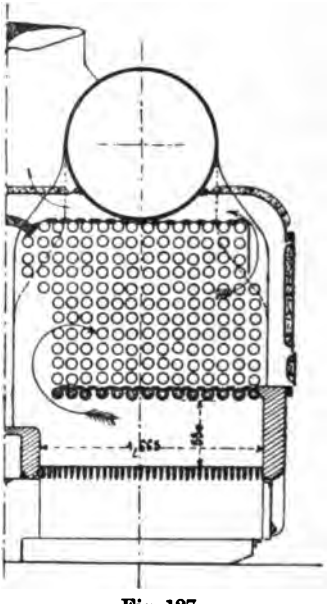

Fig. 127.

having thirteen horizontal rows of tubes, and about 12 ft. 5½ ins. for those having twelve rows; these are the ordinary dimensions, and are rarely exceeded.

Taking the *Jemmapes* as an example, the tube surface is 31·5 times, and the total heating surface 33·5 times, the grate surface.

110. *Constructive Details of the D'Allest Boiler.*—These boilers, simple in character, have only undergone slight variations in

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construction, and no fittings of a special character are used. Since the first trials of the *Bombe*, in order to prevent the hogging of the tubes which then took place, Serve tubes have been adopted for the bottom horizontal row and for the vertical row at the side of the combustion chamber. After the first few runs, the bottom tubes of the *Bombe* took a permanent curvature, the rise at the centre reaching 0·39 inch. (For an explanation, see Section 91, Fig. 102.) This sign of fatigue taking place at the outset raised suspicions as to the durability of the boiler, and especially as regards the tightness of the joints. The tubes are of steel, 3·15 inches outside diameter and 0·12 inch thick, and are simply expanded into the tube plates. Weldless tubes have been exclusively adopted since the opening of a badly welded tube on the *Jauréguiberry*.

The flat plates of the water spaces are strongly stayed together and the outside ones are provided with hand-holes opposite each tube.

After various trials, two kinds of jointing were adopted at

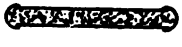

Fig. 128.

Fig. 129.

Indret for the hand-holes, one being of asbestos, with a thin metal covering (Fig. 128), and the other entirely of metal (Fig. 129).

The first-mentioned joint is composed of asbestos, tightly enclosed between two sheets of lead, with an edging of thin copper; the second is formed of a copper ring or washer between two lead ones, the three rings forming one complete washer.

The top drum is much weakened where cut away for the lower half of its circumference to form connections with the flat water spaces, and therefore the two ends are stayed together by longitudinal stays arranged in a circle around the inside of the barrel. A curved baffle is fixed inside the drum between the internal steam pipe and the water level; it acts as a steam separator, in much the same way as those in the Belleville boiler, but is much simpler in form. This arrangement was adopted

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after the trials of the *Bombe*, whose boilers gave very wet steam.

The feed is introduced into the back water space, as may be seen on reference to Fig. 125A, which shows the boiler of the *Guichen*.

The rush of all the steam from the generating tubes into the front water space, when the ship is at rest, produces a tumultuous movement of the water in this space and a big wave or surging in the top drum, whilst the water in the back space remains tranquil. This gives rise to a distortion of the water line, which varies with the rate of working, and is of great importance. Fig. 130 shows this distortion as ascertained from a trial boiler provided with windows. Two tubes connected with the two water spaces showed a difference of level, *p q*,

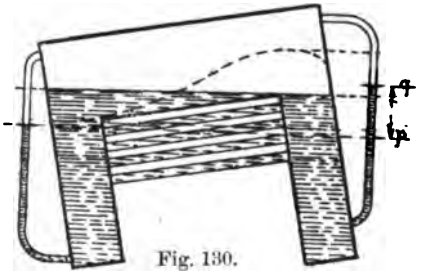

Fig. 130.

which is less than that measured from the top of the wave, and generally ranges between $2\frac{3}{8}$ and $2\frac{3}{4}$ inches. As the level is most stable in a tube connected with the back water space, the bottom tube of the low water alarm has been carried to the lower part of this space since the accident on the *Liban* in 1890.

It has also been decided since this accident to fix a fusible plug to the upper row of tubes, but a better knowledge of the variations in the water line, together with the amended position of the low water alarm and other improvements in detail, have diminished the importance at first attached to this supplementary precaution. The boilers of the *Jauréguiberry* do not appear to have been fitted with fusible plugs.

The steam on its way from the boilers to the engines passes through a reducing valve.

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111. *Results Obtained.*—Experiments made with a trial boiler at Marseilles gave the following results:—

Coal Burnt per Square Foot of Grate per hour.	Water Evaporated per lb. of Coal.	
	Old Type (without Combustion Chamber).	New Type (with Combustion Chamber).
8·19	..	10·67
15·36	6·06	10·42
20·48	6·53	..
24·99	..	8·02
30·92	..	8·75

The great superiority of the new type is in some measure due to the hot gases giving up a greater portion of their heat prior to entering the funnel, the temperature at the base of the chimney during the trials being 570° Fahr. with the old type having two horizontal baffles, and 480° with the new type. Completer combustion, as shown by the analysis made with the Orsat apparatus accounted for the increased efficiency. With the old type, carbon-monoxide was given off in such abundance that M. D'Allest thought the carbonic acid was decomposed by contact with the cold tubes, according to the simple but hardly probable reaction,

$$CO_2 = O + CO.$$

With the new type, carbon-monoxide was traceable in small quantities above the bridge, but to a quite inappreciable extent in the smoke-box.

The substitution of D'Allest for locomotive boilers on the *Bombe* has given satisfactory results. The two sets were of the same total weight, with a notable difference in the grate areas: 77·5 square feet for the original locomotive boilers, and 101 square feet for the D'Allest boilers. At the most, 1,306 horse-power could be got out of the original boilers, burning 2·87 lbs. of coal per horse-power; whereas the new boilers were much more economical, although supplying steam for 1,959 horse-power. (See table on next page.)

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Several ships fitted with D'Allest boilers have already made their trials: the *Bombe* with double-compound engines, the *Jemmapes, Chasseloup-Laubat, Bouvines, d'Iberville, Cassini, Casabianca, Jauréguiberry, Carnot,* and *Charles-Martel,* all with triple-expansion engines. The following table gives a few of the results obtained:—

——	*Bombe.*	*Cassini.*	*Chasseloup-Laubat.*	*Jemmapes.*
1. *Coal consumption Trials.*				
Boiler pressure . lbs. per sq. in.	125·0	163·5	171·5	159·3
Pressure at reducing valve „	114·61	151·05	135·58	166·98
Expansions $\Delta = \frac{D^2}{i\,d^2}$ . . .	4·39	8·6	12·59	11·86
Coal burnt (per sq. ft. of grate lbs.	21·074	20·115	10·85	14·715
Coal burnt (per horse-power . „	2·092	1·817	1·48	2·0
2. *Speed Trials.*				
Boiler pressure . lbs. per sq. in.	139·74	195·57	184·9	203·82
Pressure at reducing valve „	119·474	171·95	159·88	184·88
Expansions $\Delta = \frac{D^2}{i\,d^2}$ . . .	3·78	6·84	7·34	8·763
Coal burnt (per sq. ft. of grate lbs.	48·25	31·273	23·88	30·122
Coal burnt (per horse-power . „	2·374	1·947	1·779	2·101

Practical experience with these boilers, under ordinary working conditions, has been obtained on the passenger vessels of the Compagnie Fraissinet at moderate and regular rates of working, but the boilers fitted to ships of war have not yet seen much service. The boilers of the *Bombe* alone have been at work for some few years. When inspected in 1894, the lower tubes were found to be curved in the same way as those of the boiler tried on land in 1891, without, however, causing any accident. All the tubes were bent away from the flames, following the principle illustrated by Fig. 102. The tubes also showed a tendency to wear away on the insides near the ends, as shown by Fig. 131; from this cause over seventy tubes on the *Bombe* had to be replaced during a period of two years.

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The serious accident which occurred at the official trials of the *Jauréguiberry* has emphasised in an unpleasant manner the close and constant attention to the water level, which, on the D'Allest boiler, is necessary, owing to the form of the combustion chamber. An iron tube badly welded, or perhaps not welded at all, which had, nevertheless, been subjected to severe tests, opened out; it was the tenth tube, counting from the top, in the vertical row at the side of the combustion chamber. As at this moment there was neither a very active fire nor a high pressure of steam, the overheating which led to the accident was evidently due to shortness of water. Probably the level had not fallen so low as the tenth row of tubes, but it was sufficiently low to stop the circulation through the top drum, and as the only return for the water to the back water space was by way of the upper tubes, the result was comparative stagnation, permitting the formation of steam chambers and the overheating of some of the rows of tubes, amongst which was the one containing the defective tube.

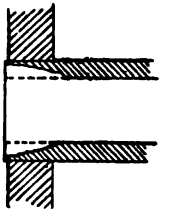

Fig. 131.

112. *Seaton Boiler.* (*First type.*)—The early type of the Seaton boiler (Fig. 132) is in many respects very similar to the D'Allest, the principal differences being as shown on the following page.

The tubes are divided into large elements, each containing four or five vertical rows of slightly inclined tubes, connecting two flat water spaces and surmounted by a cylindrical drum, thus forming a sort of narrow D'Allest boiler. Surmounting the whole is a transverse cylindrical collector connecting the different drums and serving as a common steam chamber.

The narrowness of the water spaces obviated the use of stays. The outside plates are stiffened by corrugations and are removable, thus dispensing with hand-holes opposite each tube.

The common steam chamber has the disadvantage of materially increasing the height of the boiler.

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113. *Babcock and Wilcox Boiler.*—The Babcock and Wilcox boiler is one of the oldest amongst tubulous boilers; there are

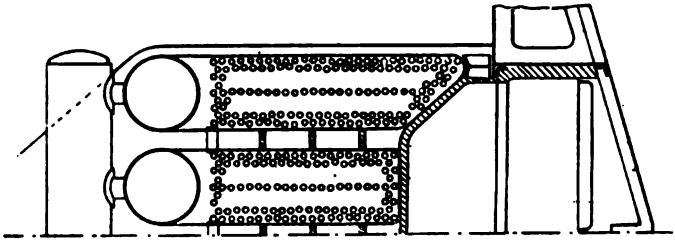

Fig. 132A.

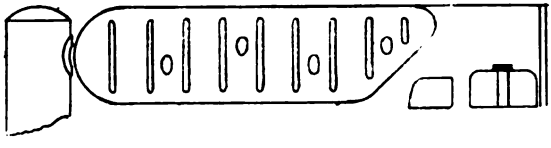

Fig. 132B.

SEATON BOILER (FIRST TYPE).

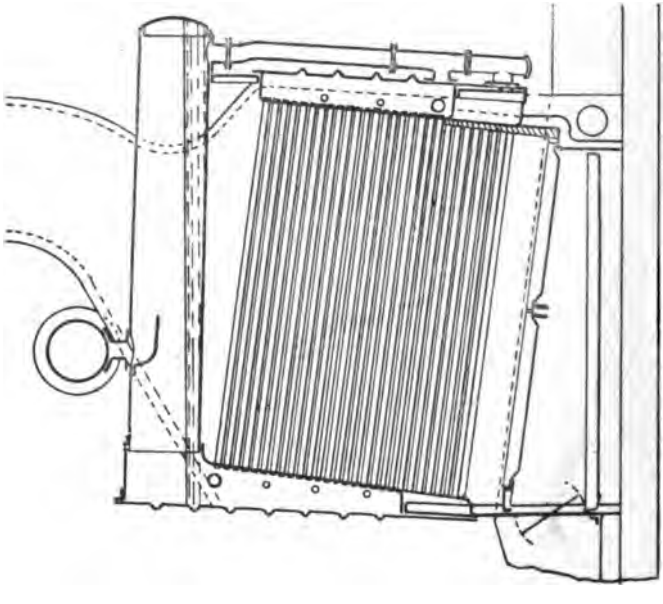

Fig. 132.

various types of this boiler which has been largely used in America and elsewhere. Up to the present, it has been almost solely employed on land, and will, therefore, be only briefly

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alluded to here. Fig. 133 represents the most recent marine type, which has been fitted to some cargo boats.

The water circulation is almost the same as in the D'Allest boilers, but the flat water spaces are replaced by rectangular headers of forged steel and of sinuous form, as seen from the

BABCOCK AND WILCOX BOILER.

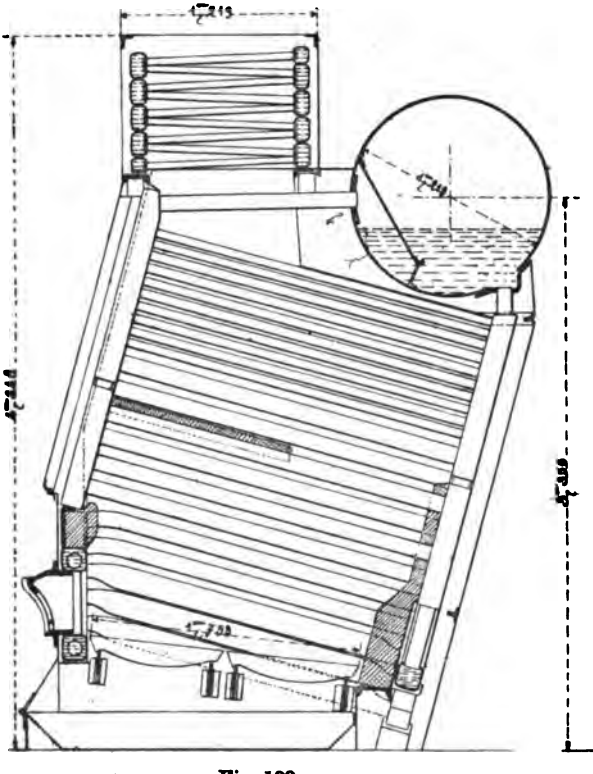

Fig. 133.

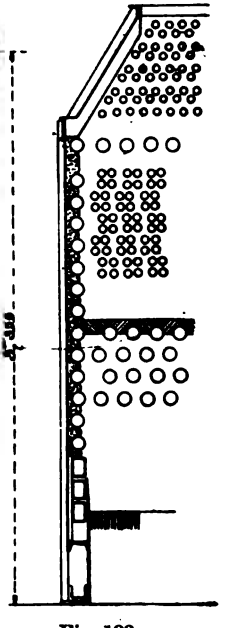

Fig. 133A.

end of the boiler. This conformation enables the tubes to be staggered and thus more effectually to break up the flames and current of hot gases. Only the two rows at the sides are set vertically so as to protect the boiler casing.

The hot gases ascend vertically across the tubes, the lower ones being large and wide apart, and thus favourably disposed

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for good combustion, while the upper ones are small and close together, and therefore well arranged for extracting the heat from the hot gases. An economiser is placed in the uptake.

Babcock and Wilcox boilers have been fitted to the s.ss. *Nero* and *Hero*, of the Wilson line, to three vessels built by Messrs. Doxford, of Sunderland, and also to the French steamer *Algérie*, of 1,282 tons. Natural draught only has been tried on board these vessels. A boiler of the same type as those fitted to the *Algérie* was tried on land in 1895 with forced draught in a closed stokehold, and gave the following results. The trial lasted twenty-four hours, burning Pocahontas coal.

Grate Area	G	38·5	sq. ft.
Heating surface	S	1551	„
Ratio	$\frac{S}{G}$	40·2	
Pressure of air in the ashpan		1	in.
Draught in the funnel		0·5	„
Total draught		1·5	„
Evaporation per sq. ft. of heating surface		9·5	lbs.
Evaporation per lb. of coal		7	„

The evaporation from and at 212° was 8·25 lbs.

The applications of the Babcock and Wilcox boiler for naval purposes, have been limited in England to the destroyer *Sheldrake*. In the United States they have been fitted to the gunboats *Annapolis* and *Marietta*, and half the boilers of the cruiser *Chicago* are of this type.

114. *Anderson and Lyall Boiler.*—The Anderson and Lyall boiler (Fig. 134) is partly tubulous and partly tubular. It is, in fact, composed of two distinct portions.

The lower portion is a kind of Joessel boiler with tubes set very wide apart, so that the flames pass over them without being unduly cooled, and their combustion is therefore not impeded. The upper portion is a complete cylindrical tubular boiler of a type long used on French pinnaces under the name of the "Bigot" boiler: in this portion the hot gases are further deprived of their heat. Flat vertical water-spaces connect the

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two portions. Fig. 134 represents a double-ended boiler of this type.

Mr. Stromeyer made some trials of this boiler, and believes its efficiency to be higher than that of any other type of tubulous boiler. He calculates that 13,810 B.T.U. are utilised per pound of coal, having a calorific value of 17,170 B.T.U., which corresponds to an efficiency of 80·5 per cent. The weight of the Anderson and Lyall boiler is its greatest disadvantage;

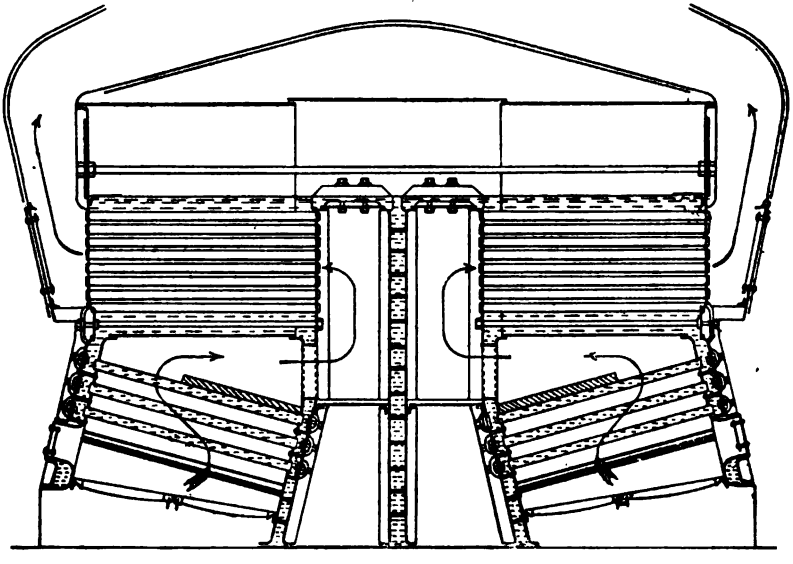

Fig. 134.

it amounts to 0·58 ton, water included, per square foot of grate area, and is about the same as that of locomotive type boilers.

The height of the boiler is also very great, even exceeding that of the Seaton boiler.

115. *Towne Boiler.*—The Towne boiler, which has been fitted to launches and gunboats in America, has narrow water-spaces at each side with a bend at the centre of their height. The tubes connect the lower portion of one water-space to the upper

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portion of the other, the two sets of tubes crossing one another at the centre. (Fig. 135.)

This novel arrangement permits an inclination favourable to a rapid circulation to be given to the tubes, and by increasing the height of the furnace is conducive to good combustion.

The Towne boiler is provided with downtakes for the return

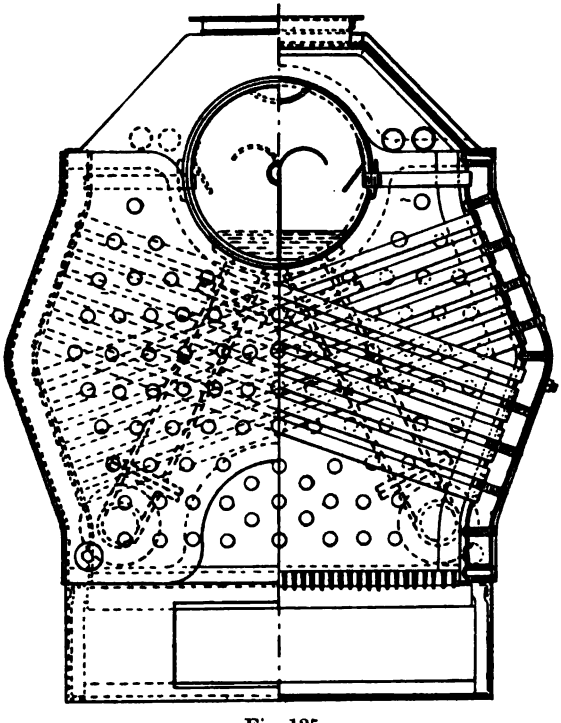

Fig. 135.

of the water, and therefore possesses some of the advantages of boilers with accelerated circulation, although its general construction more nearly resembles that of boilers with free circulation.

116. *Petit and Godard Boiler.*—The Petit and Godard boiler has a rather special form, and can hardly be classed amongst tubulous boilers with horizontal circulation; in fact, in this

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boiler the water circulates through tubes bent into a zigzag form with the straight portions inclined to the horizontal. At each side of the boiler is a flat water-space, and there are two sets of generating tubes, one for each side of the boiler.

The lower ends of the tubes are connected to the lower part

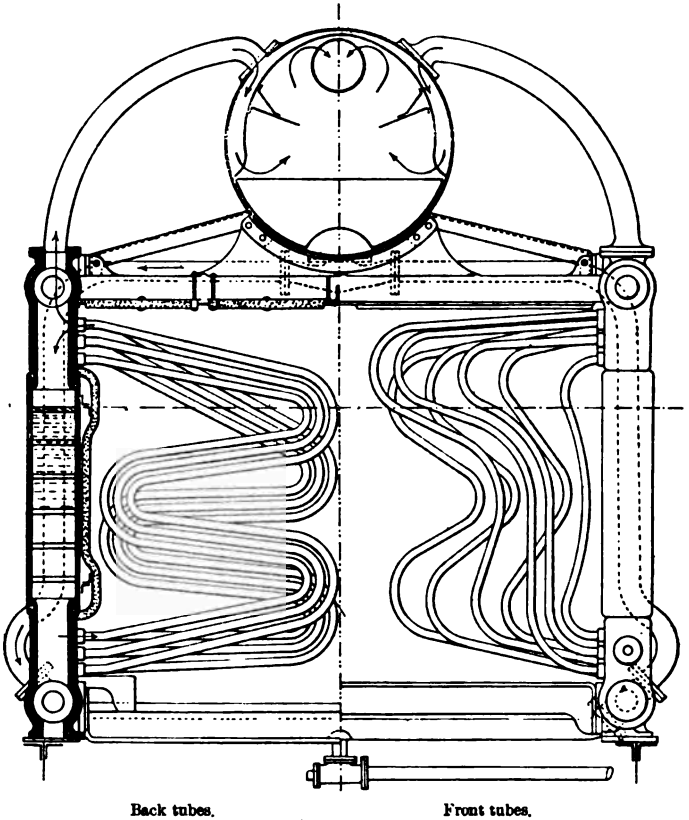

Fig. 136.

of the water-space, which serves as a water distributor, and the upper ends open into the upper portion of the water-space, which forms a steam-chamber (Fig. 136).

The coal is burnt in a firebrick furnace in front of the boiler. When using forced draught the stokehold becomes very hot and the firing difficult.

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The Petit and Godard boilers were fitted to the torpedo-boat No. 73 and on the *Bouët-Willaumez*. Trials in which the tubes near the furnace showed a tendency to overheating, due, no doubt, to the formation of steam-chambers, which rendered the work of stoking very unpleasant, led to the somewhat hasty condemnation of this class of boiler, in which the furnace is

LEBLOND AND CAVILLE BOILER.

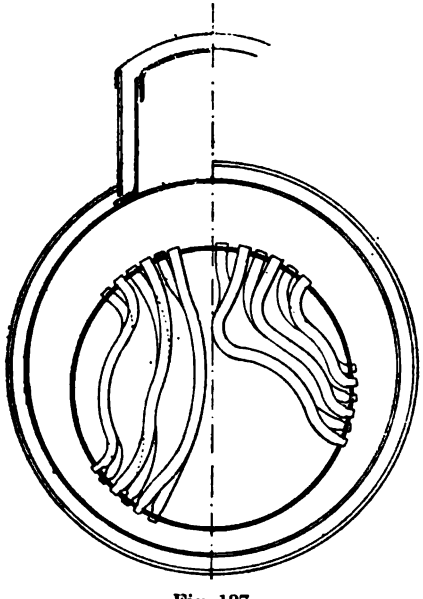

Fig. 137.

separated from the boiler itself. The boiler of the *Bouët-Willaumez* has since been altered to burn petroleum and is still at work.

The principle of separating the furnace from the boiler, so that the combustion can be completed at a high temperature in a sort of gas-heating chamber, is rational enough, and has, moreover, been advocated for a long time. The Petit and Godard boiler, although perhaps not suitable for high rates of forcing—a defect shared by all boilers with horizontal circulation—may be a good boiler under the usual conditions of working met with on shore.

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A boiler made for torpedo-boat No. 21, but not fitted, is now in use in a workshop at Brest.

The Leblond and Caville boiler may be mentioned as being analogous to the Petit and Godard boiler. It is cylindrical, with an internal furnace, and is, in other respects, an off-shoot of the Galloway boiler.

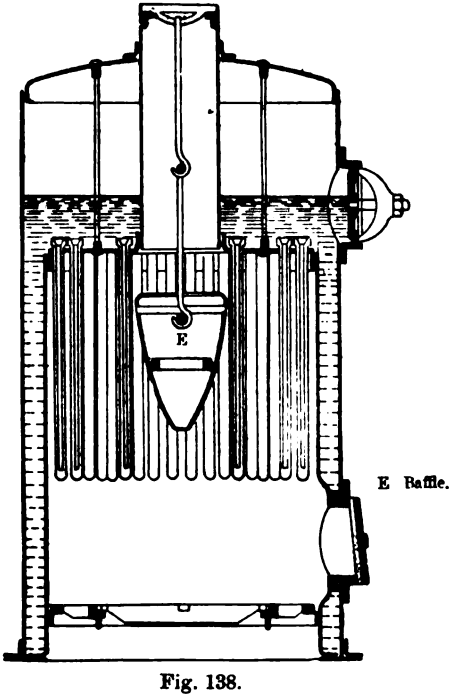

Fig. 138.

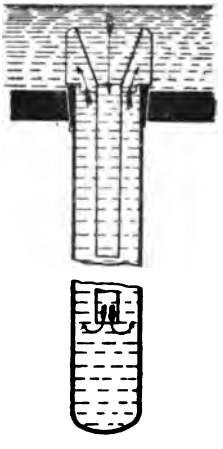

Fig. 139.

117. *Field Boiler.*—The Field boiler, with vertical water-tubes, should be mentioned as being the prototype of the Collet and the Niclausse boilers and other analogous types.

It has often been employed on board ship as an auxiliary or donkey boiler, especially when its only competitor as regards rapidity of getting up steam was the Belleville boiler.

Fig. 138 represents the boiler complete, and Fig. 139 shows one of the tubes with the direction of the circulation indicated by arrows. This boiler, with its tubes opening into a single

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reservoir, is somewhat irrational in principle. The circulation is very imperfect, owing to access to the inner tubes being cut off by the hot water and steam issuing from the annular space around them, and as a result incrustation takes place inside the lower portions of the larger tubes.

118. *Collet Boiler.—Niclausse Boiler.*—The Collet boiler, as improved by MM. Niclausse (Figs. 141 and 141A), is a combination of the D'Allest, or perhaps better still, of the Babcock and Wilcox, and the Field boiler. Each complete generating tube consists—as in the Field boiler—of two tubes, one concentrically within the other. The water from the outside division of the "header," passes down the interior tube to the bottom end of the exterior one, and returns along the

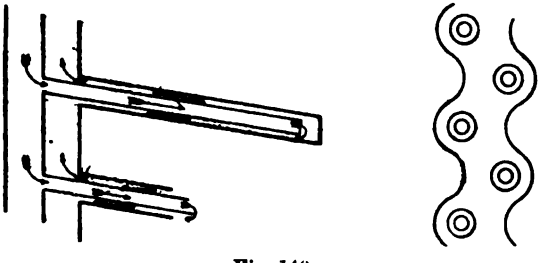

Fig. 140.

annular space between the two, where it is partly evaporated and from whence it, together with the steam generated, issues into the inside division of the "header." By thus connecting the tubes with two separate divisions in the header, there is nothing to obstruct the free entry of water to the internal tubes. Its analogy to the Babcock and Wilcox boiler consists in the use of rectangular headers placed in juxtaposition.

The Collet boiler is based on sound and rational principles, and its constructive details have been so perfected by M. Niclausse that, as now made, it presents exceptional facilities for opening up and cleaning. The Niclausse is the only boiler that we shall describe, the Collet having been rarely used in the navy.

In its present form the Niclausse boiler is composed of generating tubes, slightly inclined, around which the flames

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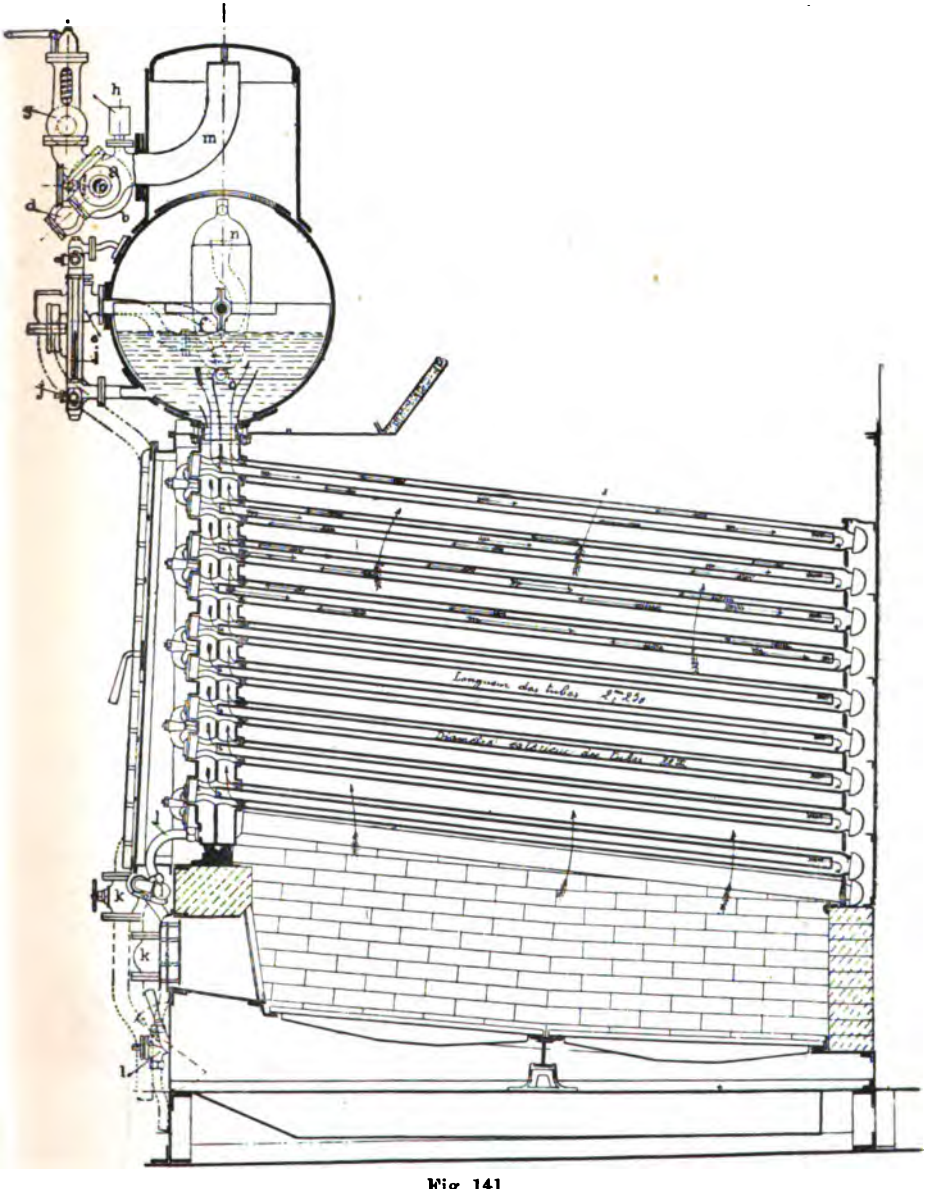

Fig. 141.

a. Main steam-pipe.
b. Main stop valve.
c. Auxiliary stop valve.
d. Steam to feed-pump.
e. Feed-check valves.
f. Scum cock.
g. Safety valve.
h. Alarm valve.
i. Test cocks.
j. Water-gauge cocks.
k. Feed-delivery valve.
l. Blow-off cock.
m. Internal steam-pipe.
n. Extractors.
o. Rings.

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ascend as in the Belleville boiler. Two vertical rows of tubes,

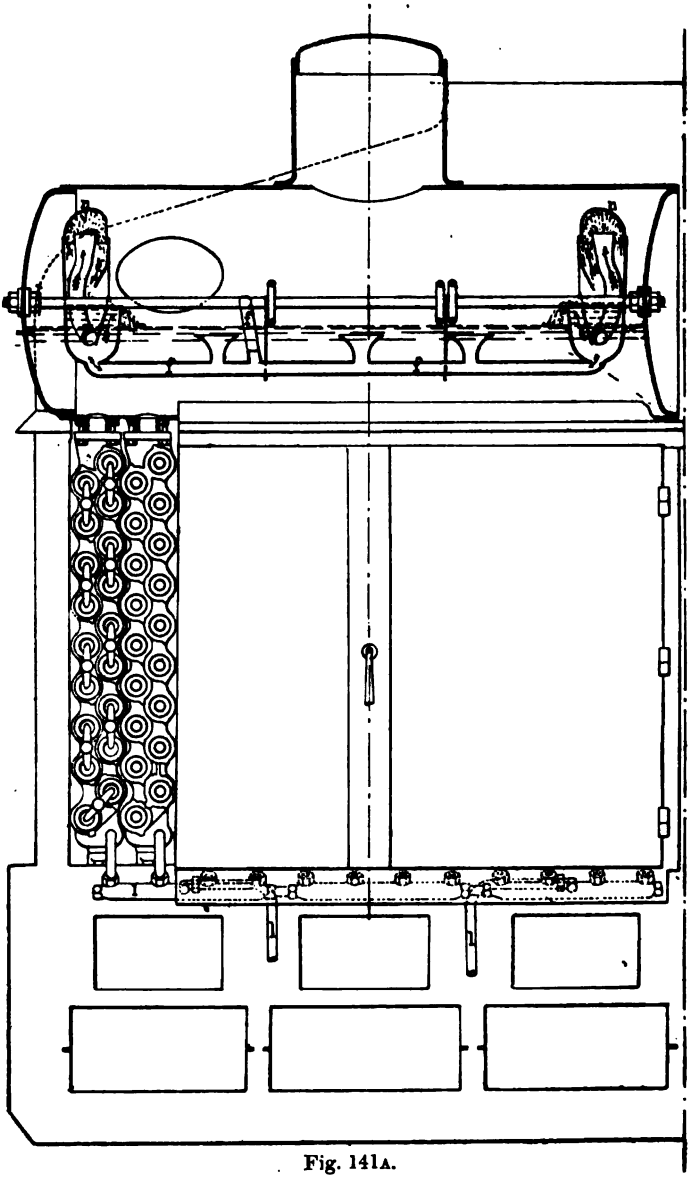

Fig. 141A.

arranged in zigzag fashion, are connected to each header. A

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small space is left between each header, through which the steam-jets for cleaning the tubes from soot are introduced.

The partitions inside the headers separating them into two parts, as also between the inner tubes, are simple diaphragms, as tightness is unnecessary. The tops of the headers are connected to a cylindrical reservoir which contains the water-level. A baffle plate, forming a continuation of the partitions inside the headers, is fitted so as to divide the ascending current of steam and water, which is here discharged into the reservoir, from the descending current of water which here commences its journey through the boiler. The feed inlet is in the cylindrical reservoir, to which are also fitted the steam- and safety-valves and the water-gauges.

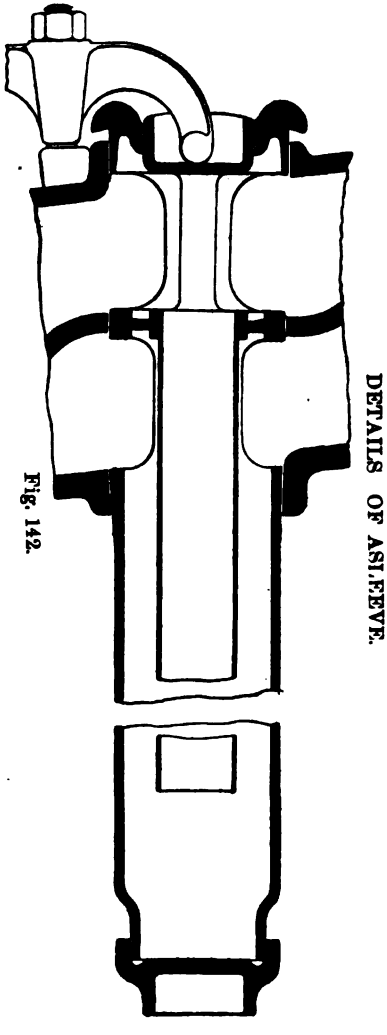

Fig. 142. DETAILS OF ASI EEVE.

The facility with which the inside and outside tubes can expand independently of each other without fatiguing any joint, has rendered possible a form of connection with the headers at once simple in construction, and permitting the ready removal and replacement of any single tube (Fig. 142).

The front ends of the tubes are attached to sleeves which form a continuation of the tube, but are so cut away as to allow a free passage to the steam and water.

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The front part of the sleeve of the inside tube is screwed into the sleeve of the outside tube and closes its front end, thereby permitting the withdrawal of the two tubes either together or separately.

Once in place, the tubes are fixed by a bolt and cross-bar bearing against the ends of the sleeves. No stress is thrown on these by the internal pressure in the boiler and each one serves for two double tubes. The surfaces where the outside sleeve makes joint with the external walls of the header are made slightly conical; the pressure exerted by the cross-bar does not put any serious stress on the bolts.

This very ingenious arrangement would appear to be capable of more general application. Its success depends solely on the accurate fitting of the joint surfaces. This arrangement of sleeves, due to MM. Niclausse, enables the long tension stays inside the tubes—introduced by M. Collet for the purpose of holding them against the headers—to be dispensed with.

Amongst other details, it may be noted that the headers and sleeves are of specially annealed cast iron. The outside tubes are now of welded steel, but it is proposed to use solid drawn ones when the price warrants it. The inside tubes are formed of two strips of thin plate, their edges being turned over one another by passing through a draw-plate. The staggered arrangement of the tubes make the gases take a zigzag direction.

The top drum is weakened by being cut away for the openings connecting it with the headers, and this part of the construction requires special attention. The feed inlet in the steam drain is surrounded by a settling chamber made of thin plate. At the bottom of this settling chamber is a discharge pipe, which also serves for the scum or surface blow-off.

The bottoms of the downtake division of the headers are each connected by a short pipe to a common pipe or collector running across the front of the boiler just above the fire-doors; each group of tubes can, therefore, be "blown off" simultaneously.

The Niclausse boiler has so far only been tried on one warship, the *Friant*, but it is being fitted to the *Elan*, and to the *Henri IV.*

The trials of the *Friant* were of special interest, because they

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formed part of a series in which the three types of boilers, Belleville, D'Allest and Niclausse, were fitted on three similar ships, the *Bugeaud*, *Chasseloup-Laubat*, and the *Friant*, and the results were therefore comparable. At first serious difficulties were encountered, and they were only surmounted after a number of exhaustive trials.

The first trials of the *Friant* showed a very low efficiency; dense smoke was given off from the funnel, and the uptakes and the base of the funnel became so hot, that in places they were entirely burnt away. Experience has shown that the fires should always be kept thin, not more than 4 in. thick, and that the stoking should be methodical, as described in Section 46. This system of stoking is a curious return to an old method rendered compulsory in the French navy in 1866, by the influence of Rear-Admiral Labrousse. Each fire is charged with about 30 lbs. of coal at intervals of two minutes. Under these conditions the results obtained on the *Friant* were as follows:—

1. *Coal-consumption Trials.*

Boiler pressure	lbs. per sq. in.	180
Pressure at the reducing valves	„	141·6
Number of expansions in the engines $\Delta = \frac{D^2}{i\,d^2}$		12·40
Coal burnt per sq. ft. of grate	lbs.	10·25
„ „ „ horse-power hour	„	1·49

2. *Speed Trials.*

Boiler pressure	lbs. per sq. in.	194·57
Pressure at the reducing valves	„	163·14
Number of expansions in the engines $\Delta = \frac{D^2}{i\,d^2}$		7·63
Coal burnt per sq. ft. of grate	lbs.	25·03
„ „ „ horse-power hour	„	2·032

A comparison of the performances of the Niclausse boilers of the *Friant*, the Belleville boilers of the *Bugeaud*, and the D'Allest boilers of the *Chasseloup-Laubat* are given in Section 157, page 351.

The following Table gives the results of experiments made at

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their works by Messrs. Humphrys and Tennant with a Niclausse boiler (land type), burning ordinary Cardiff coal:—

Grate area	19·16 sq. ft.
Heating surface	630 „

Duration of trial	8 hours.	8 hours.	8 hours.	8 hours.	4 hours.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Coal burnt per sq. ft. of grate per hour	12·94	18·96	25·31	29·2	35
Water evaporated. Actual	9·28	9·25	8·66	8·27	7·93
Water evaporated. From and at 212°	11·2	11·06	10·45	9·90	9·59

The following are the results of a series of experiments made by Mr. Jay Witham, in the workshops of Messrs. Cramp of Philadelphia. The coal used had a rather lower calorific value than that employed in the preceding tests, varying from 13,140 to 13,940 B.T.U.

Grate area	28 sq. ft.
Heating surface	1,092 „

Duration of trial	10 hours.	10 hours.	10 hours.	10 hours.
	Lbs.	Lbs.	Lbs.	Lbs.
Coal burnt per sq. ft. of grate per hour	13·7	13·6	12·8	21·9
Water evaporated. Actual	8·6	8·8	8·5	9·31
Water evaporated. From and at 212°	10·2	10·5	10·2	11·2
Total efficiency per cent.	76·5	78·7	74·3	77·5

It has been noted in Section 37 that, by the use of a closed ashpit system of forced draught, MM. Niclausse hope to rival in weight efficiency the class of boilers having accelerated circulation. They have, in fact, during a trial, burnt as much as 41 lbs. of coal per square foot of grate without sacrificing economy, although evaporating about 10¼ lbs. of water per square foot of heating surface.

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A boiler in the works of MM. Niclausse has been forced until the chimney burnt through, the tubes remaining uninjured although the evaporation is said to have reached 72 lbs. of water per square foot of heating surface. These trials are being continued by MM. Niclausse, more with the idea of showing the indestructibility of their boiler, and of dissipating the fears that might have arisen owing to the opening of a badly welded tube on the *Friant*, than in the hopes of obtaining a satisfactory economy at these high rates of combustion.

It is important to know, for the Niclausse as well as for other types of tubulous boilers, the consequences attending a fall of the water-level, sufficient to interrupt the normal circulation in the boiler. A drop in the water-level produces very different results, varying with the type of boiler.

A Niclausse boiler has been constructed with a view to its possible application to torpedo-boats, in which the external diameter of the tubes has been reduced to 1·57 in. and the ratio of heating surface to grate surface increased to 50. In this boiler the rate of combustion was as high as 81·9 lbs. per square foot of grate. The actual evaporation per pound of coal, which at a pressure of 142 lbs. per square inch was 10·6 lbs., when burning 20·5 lbs. of coal per square foot of grate, only fell to 7·6 lbs. with a combustion of 72 lbs. of coal per square foot.

The Niclausse boiler has a promising future before it; up to now, as regards facilities for internal and external cleaning, and for the replacement of damaged parts, it is incontestably superior to many other types of boilers, and has the further advantage, that the horizontal space occupied by the boiler is very small.

As the top drum runs parallel with the boiler front, the Niclausse boiler can be arranged in battery form, having only one main steam- and feed-pipe for the different boilers constituting the battery. This feature simplifies the piping and connections, as well as the management of the boilers; it is common to the Belleville and the *Lansquenet* type of Oriolle boiler, but is absent in the D'Allest boiler, and all the boilers with accelerated circulation.

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119. *Dürr Boiler.*—The Dürr boiler, of German origin, is also a derivative of the Field boiler; it is analogous to the Collet-Niclausse, but, unlike it, is not divided into elements, all the generating tubes being connected to a single flat water-space (Figs. 143, 143A, 143B). Trials of this boiler have been

DÜRR BOILER.

Longitudinal section.

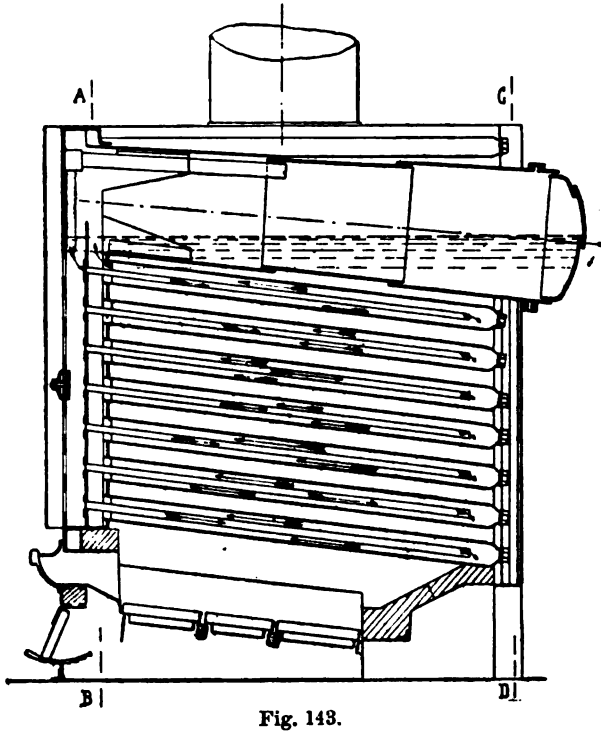

Fig. 143.

published, in which the combustion has been forced up to 70 lbs. per square foot of grate; but the efficiency must have been low, judging from what is known of the Belleville, Oriolle, Collet and other boilers, when forced at such high rates.

The Dürr boiler is to be fitted on the German cruiser *Ersatz-Freya*, of 5,600 tons; at the same time two other sister ships will be fitted with Belleville and Niclausse boilers; this series of

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trials will recall the similar ones recently made in France, on three cruisers of 3,750 tons, fitted with Niclausse, Belleville, and D'Allest boilers.

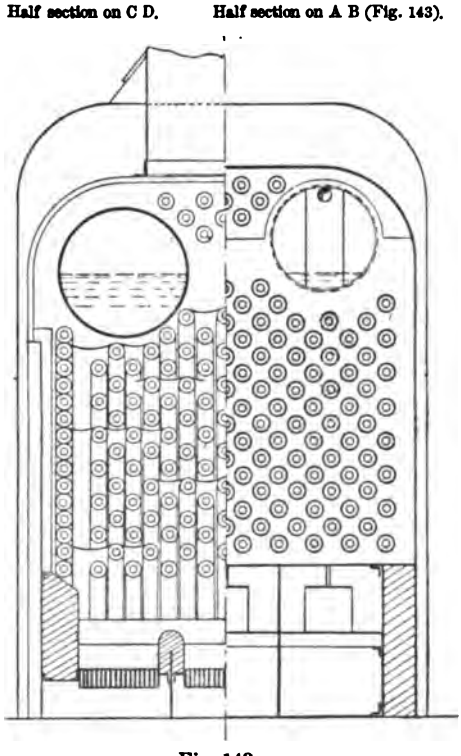

Fig. 143A.

JOINTS OF HORIZONTAL TUBES.

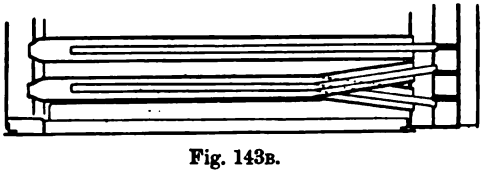

Fig. 143B.

120. *De Dion-Bouton-Trépardoux Boiler.*—This boiler is at present in use on the torpedo-boat No. 18, and the 1,000 horse-power torpedo-boats 167, 168 and 169. It is of a vertical

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cylindrical form and is composed of an annular water space, connected by radiating tubes to an inside cylindrical reservoir (Fig. 144). The upper tubes, which only contain steam, are soon wasted through, and all the tube-joints, even those in the lower rows at the inner ends, are very apt to leak. Further, for a tubulous boiler, it contains a large quantity of water, and

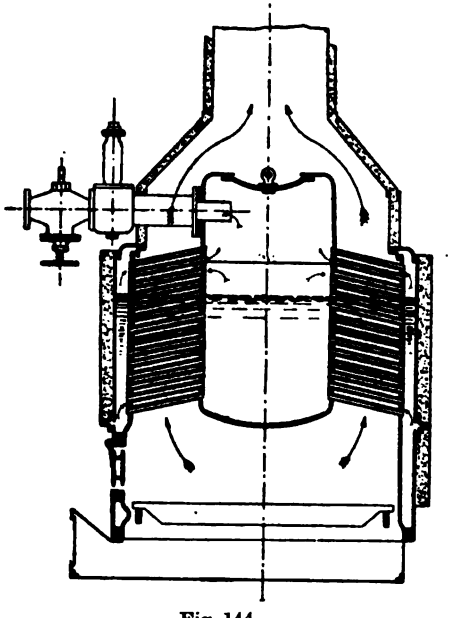

Fig. 144.

consequently its weight is high, being 0·356 ton per square foot of grate, of which the water accounts for 12 per cent.

Trials made in 1893 gave satisfactory results. The torpedo-boat No. 167 developed 1,118 horse-power, with a grate area of 43·4 square feet, burning 2·6 lbs. of coal per horse-power; at the most economical speed, when developing 141 horse-power, only 1·19 lbs. were burnt. As these boilers have not proved satisfactory in service, their use on torpedo-boats appears likely to be abandoned; on the other hand, they have given excellent results when used on steam carriages.

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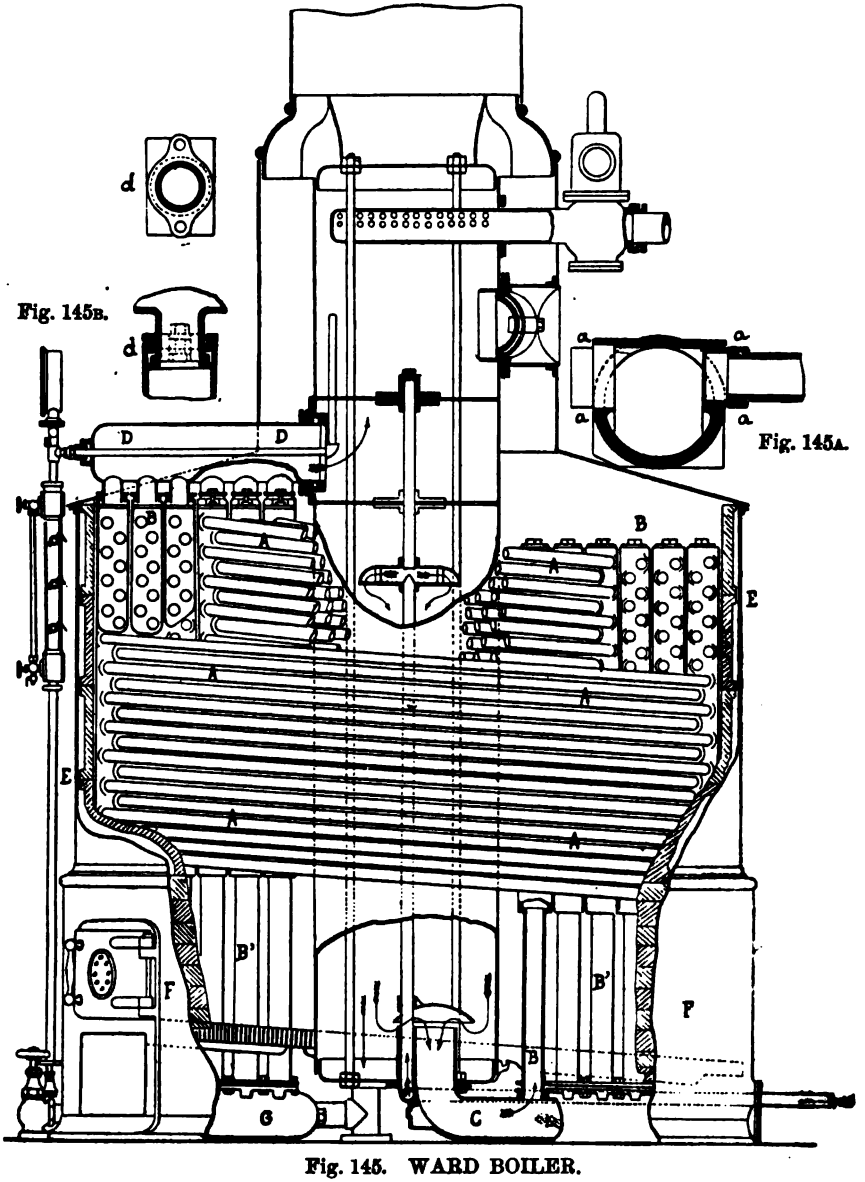

Fig. 145. WARD BOILER.

NOTE.—The boilers of the *Monterey* are of this type, but larger, having 18 concentric rows of tubes instead of 12.

AA. Coils of tubes connected to the vertical headers BB, by screwed ferrules *aa*.
BB. Vertical headers connected at their lower ends to tubes of smaller area B'B', among which the gases circulate.
aa. (Fig. 145A). Ferrules forming the connection between the tubes A and the headers B.
CC. Bottom horizontal collectors, to which the tubes B'B' are connected by fixed joints.
DD. Upper horizontal collector, to which the vertical headers BB are connected by expansion joints.
dd. (Fig. 145B). Expansion joints; stuffing boxes packed with asbestos connecting the collector D with the headers BB. The gland bolts have flat T-heads lodged in the thickness of the lugs formed on the box.
EE. Casing of plate, 0·1 in. thick, lined with hollow bricks 1¼ in. thick.
FF. Casing of plate, 0·118 in. thick, lined with hollow bricks 4¼ in. thick.
QQ. Settling drum.

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121. *Ward Boiler.*—The largest and most important applications of boilers with free circulation, are undoubtedly to be met with in the French navy, which has on this account been taxed with undue temerity.

Acting with greater prudence, the United States navy has made an interesting application, on board the *Monterey*, of the Ward boiler in combination with cylindrical boilers.

The Ward boiler is somewhat original in construction, resembling in many respects the Trépardoux boiler. Its water tubes are in the form of semicircular concentric rings, and are connected at either extremity to a row of vertical tubes or headers. These two rows of vertical tubes forming the headers are placed radially on opposite sides of the central reservoir, and take the place of the flat water spaces found in boilers of the Joessel system. The general form of the boiler is cylindrical; the grate is circular, and composed of segments placed around the central vertical reservoir (Fig. 145).

This reservoir is divided into two portions by a horizontal partition; the feed-water finds its way down to the horizontal collector, and the steam issuing from the generating tubes is received at the upper end of the central reservoir.

All the joints are very simple, and the entire boiler should have great elasticity owing to the curvature of the generating tubes. Its principal disadvantage is in the circular form of the grate, which renders the stoking difficult, especially at the sides, and impossible behind the central reservoir, unless there is more than one fire-door.

The Ward boiler is one of the lightest in existence. The two boilers of the *Monterey*, with a total of 73·74 square feet of grate surface, weigh 15·08 tons without water, and 17·5 tons with water, which makes only 0·238 ton per square foot of grate.

In the trials of the *Monterey*, the Ward boilers, constantly working under the same conditions of firing as the cylindrical return tube boilers, gave complete satisfaction. Under forced draught, the production of steam was limited by the care which had to be taken to prevent the cast-iron grates falling down, and not from the apprehension of any danger due to the joints giving out.

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As a result of the experience gained on the *Monterey*, Commodore Melville has declared himself ready to extend the application of tubulous boilers in the American navy.

122. *Charles and Babillot Boiler.*—A distinctive feature of this boiler (Fig. 146) is that the tubes are concentric, the gases

CHARLES AND BABILLOT BOILER.

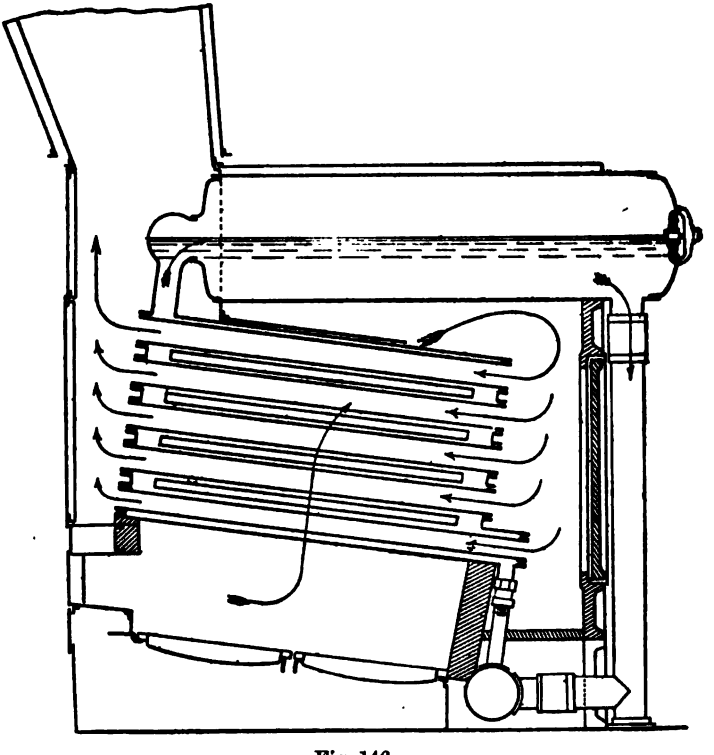

Fig. 146.

passing first around the outside tubes and then running along the inside ones; it is an adaptation of one of M. Joessel's early inventions, which has since been abandoned.

The large heating surface and the lightness of this boiler attracted attention at the Exhibition of 1889, and it was then decided to fit boilers of this type on the torpedo-boats *Sarrazin*

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and *Tourbillon*, as well as on the 1,000 horse-power torpedo-boats, Nos. 155 to 160. The narrow annular spaces between the tubes impeding the circulation led to the formation of steam chambers, and made this boiler extremely dangerous when forced at the high rates usual on torpedo-boats. The repeated occurrence of accidents, owing to the lower rows of tubes becoming red-hot, led, after the accident in January, 1894, on board the *Sarrazin*, to the final condemnation of the boiler.

123. *Various Types.*—There are a great number of other types of boilers, more or less analogous to the preceding, that need only be briefly mentioned here, because they have been little, if at all, used for marine purposes.

There are boilers of English design, amongst which Mr. Watt's may be mentioned, which are similar in design to the Joessel-D'Allest boiler.

The Kelly boiler is a sort of Niclausse boiler, without divisions in the headers; the tubes are divided into two portions by a partition running down them—an arrangement which appears very inferior to the employment of concentric tubes.

In the Bourgeois-Leucauchez boiler, there is only one header divided into two parts; the tubes are bent into a V form, the angle being very acute. The water enters the bottom branch, while the steam is discharged by the top one. This arrangement is common to other types, amongst which may be noted the Terme-Deharme, in use on the Parisian river steamers, which has the peculiarity of having V's of three branches.

The Montupet, Menay, Lane, and Hérisson boilers are amongst those working on the same principle as the Field boiler, and therefore under similar conditions to the Niclausse boiler; the last one in form and general arrangement resembles the De Dion-Trépardoux boiler.

Finally, some few types should be mentioned, having coils or their equivalents, and working in much the same way as the Belleville boiler. These should perhaps have been noticed at the end of the preceding chapter. One of them, the Isoard, patented in 1849, is of historical interest. Mr. Herreshoff has

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for a long time employed a boiler composed of a double spiral, the coils of which are in contact and form a wall surrounding the fire; it was noted in Section 104 that the water circulated in an unusual manner.

In 1883, Mr. Thornycroft constructed a coil boiler, which was tried on a small boat, called the *Peace*, with very good results.

The Root boiler is in some respects similar to the Belleville, but has tubes specially provided for carrying off the steam, which distinguishes it from coil boilers properly so called.

The different boilers which have just been considered or enumerated do not by any means fill the list of boilers with horizontal or almost horizontal circulation. Recent exhibitions, that of Chicago in particular, have shown the existence of a large number of other types, of which several are applicable to marine purposes.

Boilers with free circulation, as well as those with limited circulation, are continually being improved. Up to the present they have only been adopted for use under moderate rates of forcing, but several of the principal makers are hopeful of their success under higher rates, and are prepared to enter into competition with the class of boilers having accelerated circulation.

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CHAPTER XIII.

BOILERS WITH ACCELERATED CIRCULATION.

124. *Movement of Water in a Circuit of some Height.*—The characteristic feature of all boilers having accelerated circulation is the creation and maintenance of a current of steam and water moving with a very much higher velocity than that at which the steam can possibly pass through the almost stagnant water in a Belleville boiler, or than that with which the steam can drag the water through a boiler having free circulation. The steam-bubbles are detached from the heating surfaces, and carried towards the reservoir as quickly as produced, and are unable to accumulate and form steam-chambers, however high the rate of evaporation.

The means of ensuring this consists in causing the forces by which circulation is usually and naturally produced, to act upon a column of some height, and so disposing the downtake tubes returning the water from the top to the bottom reservoir, that they form a continuous circuit with the tubes carrying the steam from the bottom to the top.

The laws governing the movement of water containing steam-bubbles, in a partly heated circuit, were for a long time very little understood. They have been carefully examined in some recent works and papers, amongst which may be noted, "Traité des Chaudières à Vapeur" of M. Bellens, "Les Chaudières Marines," by M. de Chasseloup-Laubat, a paper in the transactions of the "Société Technique Maritime," by M. Brillié, and various articles in the *Engineer*; and they have been the object of some interesting experiments on the part of several engineers, amongst whom Yarrow, Thornycroft, and Watkinson may be mentioned.

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The movement of liquids in a complicated circuit can only be determined by actual experiment; although the velocities cannot be obtained, *a priori*, by calculation, yet they furnish us with useful information regarding the nature and relative value of the forces tending to produce movement.

125. *Effects due to the Expansion of Water.*—Let us first consider the effects of a difference of temperature in a tubulous circuit such as *a c b* (Fig. 147).

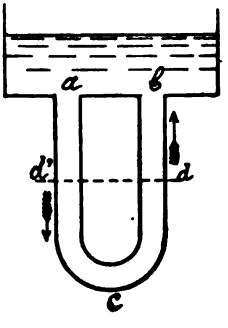

Fig. 147.

Let t be the temperature of the liquid. Suppose that at the point d, which is at a distance h below the upper orifice of the tube, the temperature is raised and becomes T. A current will be immediately set up and will be permanent when the column $d\ b$ has become filled with hot water. The force tending to produce movement, measured in height of water, is

$$p = h\left(\frac{1}{1+at} - \frac{1}{1+a\mathrm{T}}\right).$$

or, neglecting the term in a^2.

$$(1) \qquad p = h\,\frac{a\,(\mathrm{T}-t)}{1+a\,(\mathrm{T}-t)};$$

which is sensibly proportional to $\mathrm{T}-t$. The velocity of the current becomes constant when the resistance of the circuit equals the force p.

If the point d falls towards c, the height h increases, and the current is accelerated. If the point d, to which heat is applied, is then carried upwards along the branch $c\ a$, the velocity of the current is diminished but its direction remains unchanged. When, for instance, the heat is applied at d', which is at the same height as d, the difference in pressure resulting from the difference of temperature t in $d'a$ and T in $d'cdb$ has the same value p as in the case just considered, and the velocity of the two currents would be the same. To ascertain the direction of the current

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it is therefore not sufficient to know which branch is heated, but which was heated first.

Supposing that, the source of heat being at d and the current moving in the direction of the arrows, a fresh source or sources of heat are introduced between d and b, the movement will be accelerated. For instance, there will be a higher velocity with two equal sources of heat at d and d' than with one source only at d—a result which at first sight would appear paradoxical.

The difference of pressures p given by the formula (1) cannot be great, owing to the smallness of the coefficient a; it should be particularly small in tubulous boilers, because the difference in temperature of the ascending and descending columns can hardly exceed 9° Fahr. when once the circulation is well started. Assuming T − t equals 9°,

$$p = 0{\cdot}0005\ h.$$

126. *Effects due to the Production of Steam-Bubbles.*—The rapid circulation in the class of boilers now under consideration is due to the action of the steam-bubbles in the ascending portion of the circuit.

A steam-bubble of a specific gravity δ, in a liquid of a specific gravity Δ, supposing there is no resistance to its movement, will rise with an acceleration W determined by the equation:

$$\frac{\delta}{g} W = \Delta - \delta, \tag{1}$$

in which δ in the second expression is negligible in the presence of Δ. There remains, therefore,

$$W = g \frac{\Delta}{\delta}. \tag{2}$$

For example, with a temperature of 368·5° Fahr., and a pressure of 170·7 lbs. per sq. in, we get

$$\Delta = 0{\cdot}887$$
$$\delta = 0{\cdot}006$$
$$W = 4{,}760 \text{ ft. per sec.}$$

The resistance offered by the liquid at once checks this

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enormous acceleration, and limits the velocity of the bubbles through the water to a slow and uniform movement.

Let us consider the movement of bubbles of a diameter D passing through the water with a velocity V and experiencing a resistance R, the same as if they were solid balls. The value of R in terms of the velocity V, is, in default of proof to the contrary, given approximately by the equation—

$$R = \varpi \times \tfrac{1}{4}\ 0{\cdot}95\ D^2 \times V^2. \qquad (3)$$

The force acting on the bubble is exactly

$$62{\cdot}4 \times \tfrac{1}{6}\ \varpi\ D^3\ (\Delta - \delta). \qquad (4)$$

When the movement is uniform the resistance is equal to the force producing movement, hence

$$\cdot 95\ V^2 = 62{\cdot}4 \times \tfrac{2}{3}\ (\Delta - \delta)\ D.$$

Giving to $(\Delta - \delta)$ the value 0·881, since the foot and pound have been taken as units in formula (3), we have—

$$V^2 = 40\ D.$$

The velocities given by this formula are low, whatever the diameter of bubble, and are insignificant when compared with the velocities of the current of steam and water recorded by various experimenters upon tubulous boilers. Thus bubbles of 0·79 in. diameter would have a relative velocity through the water of 1·57 ft. per sec. and bubbles of 0·079 in. diameter a relative velocity of 0·52 ft. per sec. The uncertainty as to the exact value of the resistance R in no way vitiates the preceding general conclusions.

It is interesting to note the volume of steam and the corresponding number of bubbles produced in a tube. Boilers with accelerated circulation can evaporate 10·24 lbs. of water per square foot of heating surface per hour; this gives 104 lbs. or 27·7 cubic ft. of steam at 171 lbs. pressure per square inch in a tube of 1·18 in. internal diameter and 3·28 ft. long. In such a tube 52 bubbles of 0·79 in. diameter would be produced per second, or 52,000 bubbles of 0·079 in. diameter.

Applying these calculations to cases where the pressure reaches 284 lbs., about the average for tubulous boilers, the

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figure relating to the volume of steam should be reduced in the proportion 0·621. The value $\Delta - \delta$ becomes at the same time 0·877.

Bubbles moving at a uniform velocity encounter a resistance to their passage through the water of

$$62{\cdot}4 \times \tfrac{1}{6}\, \varpi\, D^3\, (\Delta - \delta),$$

equal to the force with which the bubbles react upon the water. The sum of these reactions, however, distributed throughout the particles of the liquid has the same effect as a reduction in the specific gravity of the liquid; this may be demonstrated by a simple experiment, which also shows that the increase in

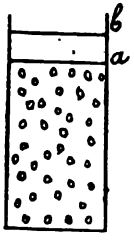

Fig. 148.

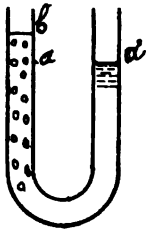

Fig. 148A.

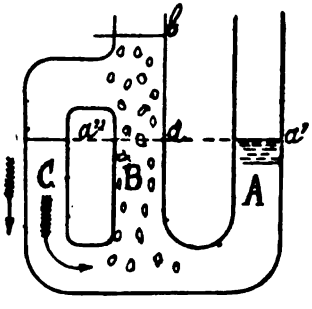

Fig. 149.

hydrostatic pressure is sensibly equal to the unbalanced forces acting upon the bubbles and causing them to rise.

If a cylindrical vessel containing water is placed upon a balance, and steam-bubbles have just commenced to form and rise with a uniform velocity, no change in weight will be indicated. The level will rise from a to b, owing to the displacement of the bubbles (Fig. 148); the height h will become h_1; the mean specific gravity δ will become δ_1; and therefore,

$$\delta_1\, h_1 = \delta\, h\,. \tag{6}$$

If there had been an outlet at a the pressure on the bottom of the vessel would have been reduced in the proportion—

$$\frac{h}{h_1} = \frac{\delta_1}{\delta}.$$

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Similarly in a U tube, of which one branch only contains bubbles (Fig. 148A), the level in this branch will rise from a to b while remaining stationary in the other branch. There is therefore equilibrium at the bottom of the syphon; but if an opening be made at a, there will be an overflow due to the difference of pressure—

$$h_1 - h = h\left(\frac{\delta}{\delta_1} - 1\right). \tag{7}$$

Let us now consider the case of a U tube as Fig. 149, having provision for circulation in the shape of a return tube,

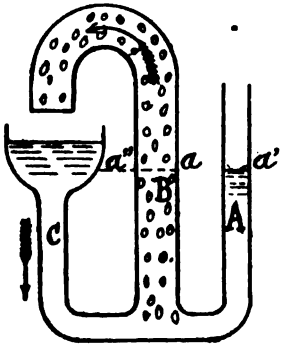

Fig. 150.

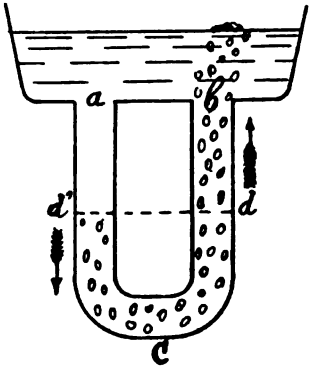

Fig. 151.

or downtake C, which is not heated and is in communication with the branch B, in which bubbles are produced.

Without steam-bubbles, the level in the tubes, when at rest, will be the same, a' and a'', and the columns of water in A and C will be in equilibrium with the column of water and steam in B, where the level is at b. On account of the communication between C and the top of B, the pressure at the bottom of C will be increased by the difference in head $h_1 - h$, and circulation will take place due to this difference. The current will attain its normal velocity when the resistance opposed to its movement counterbalances the difference in head $h_1 - h$.

Circulation will also be established if the branch B delivers into the branch C, as shown by Fig. 150, but under different circumstances. This arrangement, shown in Fig. 150, is conducive to a steady and uniform rate of circulation.

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There will be a discharge from the extremity of the tube B on account of the difference of level between this orifice and the height of the column in C, necessary for equilibrium. This case represents the mode of circulation of several types of boilers, and in particular that of M. Sochet, which was the first having accelerated circulation.

The statements previously made regarding the permanence of the currents produced by an initial difference of temperature in the two branches of a circuit *a c b* (Fig. 147) apply equally to the currents produced by the movement of steam-bubbles. We must, however, suppose that the velocity of the water is in all cases greater than that of the bubbles relatively to the water, the movement always taking place in an upward direction; if this condition is not fulfilled, the direction of the current might be reversed.

If we again take the vessel shown in Fig. 147, and heat the branch *c b* of the tube *a c b*, at a point *d*, so as to produce steam-bubbles at this point (Fig. 151) a current will be formed under the action of a hydrostatic pressure equal and opposite to the resistance offered by the water to the passage of the bubbles. If the point *d* is lowered, the number of bubbles contained in the tube will be increased, and the velocity of the current will also be increased. If the point *d* now passes to the left branch, the velocity of the current will be decreased, but without any change in its direction, the direction of motion originally set up being maintained, whether the source of heat is applied at *d'* or *d*. The application of additional sources of heat, in whatever positions, will, within certain limits, increase the velocity of the current.

It may be noted that the current set up by the production of steam bubbles, produced at a constant rate, should be of a more permanent and uniform character than that due to the lowering of the specific gravity of the ascending column. In fact, if a reduction of velocity takes place, the steam-bubbles accumulate in greater quantity in the ascending column, and the difference in specific gravity in the two columns increases by virtue of the reduction in velocity. There are thus two forces at work tending to restore the circulation to its normal velocity.

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127. *Comparative Effects of Evaporation and Expansion.*— The principle of the *entrainement* or setting in motion of the water by the action of steam-bubbles, being thus established, the head of water corresponding to the action of the bubbles can be calculated in a simple manner by assuming certain not improbable hypotheses regarding the velocity of circulation of the water. Again considering the tube of 1·18 inches internal diameter, and generating per hour and per foot of length, 27·72 cubic ft. of steam, of a specific gravity of 0·006, if the tube heated is 6·56 ft. long it will deliver 55·4 cubic ft. of steam per hour at its upper orifice. Supposing that, while heated, the velocity of the current of circulation is 6·56 ft., the total output of the tube is 0·05 cubic ft. per second, or 180 cubic ft. per hour. The mixture of water and steam discharged from the upper orifice is therefore composed of one part of steam and two of water. The water is thus subjected to a circulating force which, at the top of the tube, amounts to a third of the specific gravity of an equal column of solid water without steam-bubbles, that is to say, about a thousand times greater than the effect produced by a rise in temperature of 9° Fahr.

The above reasoning is applicable to cases where, instead of generating steam, bubbles of gas are introduced at uniform rates at the point d; this method has been used by Mr. Yarrow for the purpose of his experiments. Steam-bubbles possess the peculiarity of condensing, and of partially reforming while rising and falling, owing to variations of pressure. A special case, where the current is due to the production of steam-bubbles, and not to the heating of the liquid, is that where the tube is of such a small diameter that the bubbles fill the whole section.

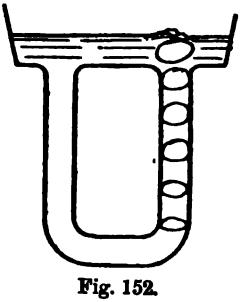

Fig. 152.

The liquid column is then broken (Fig. 152) and if there were no return tube an upward movement would be impossible, contrary to the case illustrated by Fig. 148. Supposing circulation to have already been established, the fall of pressure produced would be equal, as in the preceding cases, to the

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reduction in the mean specific gravity of the ascending column, only in this case the reason for the fall of pressure is more evident than in the preceding case. The resistance opposed to the circulation, and consequently the laws governing its velocity, would be very different to those in the case of Fig. 151.

128. *History of Boilers with Accelerated Circulation—Sochet Boiler.*—When a new form of boiler or other apparatus suddenly becomes extensively adopted, it is frequently discovered that long ago there existed examples, which in their day received but little attention. Such instances are not wanting in connection with the type of boiler now under consideration. According to Mr. Seaton's "Manual of Marine Engineering," there existed in 1827 a tubulous boiler composed of a steam reservoir and two steam and water reservoirs connected by tubes, the arrangement being strikingly analogous to that of some of the most recent examples.

The introduction on a practical scale of boilers with accelerated circulation for marine propulsion is largely the work of Captain Du Temple. He was, however, anticipated by M. Sochet, Director of Naval Construction at Cherbourg. The result sought by M. Sochet was simply the production of a boiler with rapid circulation; in fact, this was the name he gave to his boiler. His object was to prevent the deposition of hard adherent calcareous deposits upon the heating surface, and not with a view of avoiding the formation of steam chambers at high rates of evaporation, which were not then contemplated. His idea was that the marine salts would solidify in a finely divided state, be carried over by the circulating current, and deposited in an extractor or settling drum, from whence they could be discharged by blowing off. The problem was to construct a marine boiler capable of being worked at a high pressure in connection with jet condensation.

The Sochet boiler, primarily intended for service afloat, was only tried on land for workshop purposes. Figure 153 shows its general arrangement, which exactly corresponds to that now universally adopted for this type of boiler. The circulation is complete, the steam being produced in the ascending portion of

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the current, and the water returned by a large external down-take. It will be noticed that the steam is discharged above the water-level in the reservoir, as in the Thornycroft boiler.

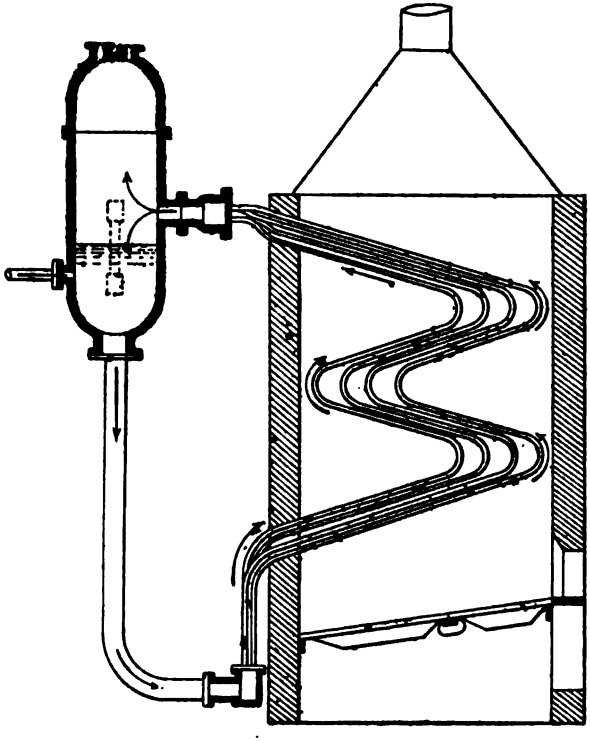

Fig. 153.

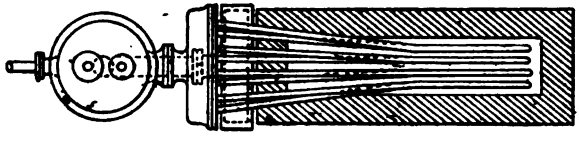

Fig. 153A.

The Sochet boiler worked at a pressure of 71 lbs. per sq. in. and evaporated 7·35 lbs. of water per lb. of coal, while burning 15.36 lbs. of coal per square foot of grate per hour.

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The grate area was 5·38 sq. ft., and the heating surface 75·35 sq. ft.

At the date at which it was put to work, the Sochet boiler, no doubt, appeared to require very delicate handling; besides, it offered no great advantage when used on shore, and was abandoned about 1859 and replaced by an ordinary boiler.

M. Sochet, who was the Author's chief in 1862, spoke very little of his boiler, but later on, the Author heard it referred to in the boiler shop where it was well remembered; the manager of the shop, M. Bigot, a very capable engineer, fully appreciated the advantages of rapid circulation for light boilers containing very little water. M. Du Temple does not appear to have had any direct knowledge of the experiments made by M. Sochet, but the workmen first employed by him had seen the boiler just described, and this probably accounts for the similarity in shape of the curved tubes shown in Fig. 153, and those of the early Du Temple boilers.

129. *Du Temple Boiler.—Original Form.*—Commander Du Temple designed his first boiler with the object of applying it to purposes of aerial navigation. It was designed with a view of supplying steam to an engine driving the helical propeller of a kind of aëroplane, an invention to which M. Du Temple devoted the whole of his fortune and a part of his life, particularly after 1876, when he retired from political life. The aëroplane was a failure, but the boiler survived. In 1878, it was fitted to a few launches, and afterwards to some torpedo-boats, and has now become the most extensively adopted type of boiler for use under high rates of forcing, whether in its early form, or as altered by different makers. Unfortunately, this has taken place at the moment when its inventor has just passed away.

The general form at first given to his boiler by M. Du Temple has not since been departed from, and is similar to that adopted by the majority of other makers. Two small water-chambers at the sides of the furnace form the lower portion of the boiler. The steam reservoir is placed above, with the water-level at about its centre. The generating tubes connect the steam and

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water reservoirs and discharge below the water-level. Large external downtakes at the front and back of the boiler serve to return the water from the upper to the lower reservoirs, and complete the circuit of circulation. Fig. 154 represents this arrangement, and at the same time shows several details which have for a long time been in use, and are also embodied by the inventor in his last patents in 1890.

The distinguishing characteristics of the Du Temple boiler properly so called, when compared with the improved and perfected forms which have since appeared, are (*a*) the use of tubes bent into several folds with five straight portions, but slightly inclined to the horizontal and successively crossed by the hot gases; and (*b*) the use of cast-iron bottom chambers of rectangular section. The furnace gases ascend almost vertically. At first, Du Temple attached great importance to the use of very thin and small tubes of about 0·4 in. diameter. He found that by their use he could obtain a larger heating surface, and also a minor advantage, in the facility with which a burst tube could be stopped by simply closing it together near the ends by means of a pair of pincers. He was himself, however, obliged to abandon this primitive method of tube-stopping. The tubes of the boilers for torpedo-boats Nos. 130 to 144, ordered in 1889, were of 0·51 in. internal diameter, and about 0·67 in. external diameter. Du Temple retained till the last the cast-iron bottom chambers, which were provided on the outside with a number of small hand-holes.

The disadvantages of the Du Temple boiler in the form which its inventor finally gave to it, principally affect its durability. The circulation in the very sinuous generating tubes was comparatively slow, from which circumstance arose the danger of the formation of deposits, especially in the nearly horizontal portions next to the bottom reservoirs, and also the danger of the formation of steam chambers in the tubes. As soon as an obstruction commenced to form in a tube, the circulation was still further retarded and the danger increased, so that the tube was bound to burn through in a very short time. The *Dragon* gave occasion for complaints of this nature whilst serving with the squadron, and the same thing occurred on the three torpedo-

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boats Nos. 186, 190, and 191, during the trip they made from Cherbourg to Toulon in 1895. It should, however, be mentioned that the engineers, who were unaccustomed to the management of

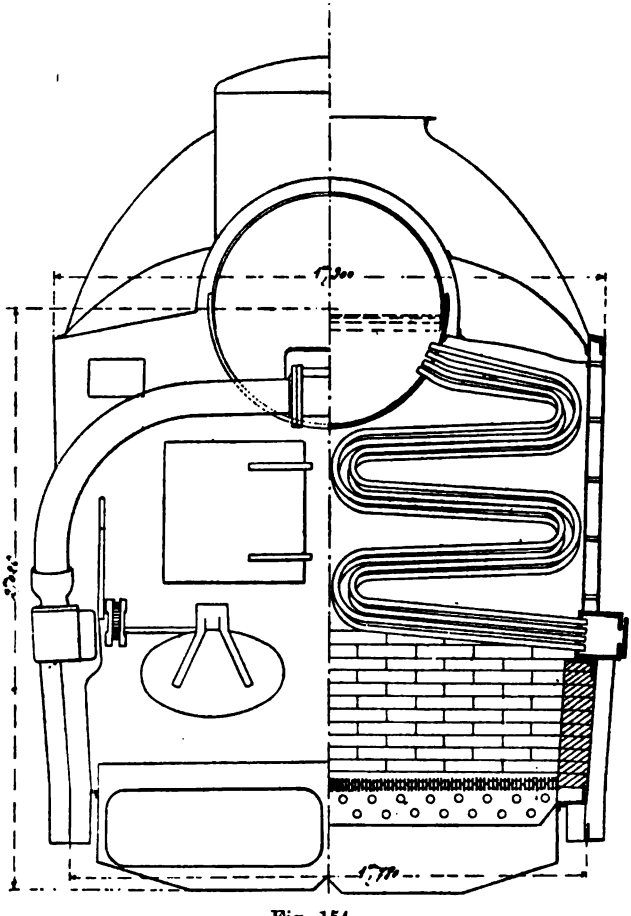

Fig. 154.

tubulous boilers, did not take sufficient care to ensure the purity of the feed-water, and to maintain the water level. The accident to the boiler of the *Averne*, where the lower portions of the generating tubes were entirely burnt away during a passage from Cherbourg to Brest, can only be explained by a prolonged shortness of water.

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The early Du Temple boilers suffered from the smallness of their combustion chambers, which were hardly larger than those of the Belleville boiler. Owing to this, combustion was incomplete, due to cooling of the gases by premature contact with the generating tubes, and at high rates of forcing gave rise to excessive flaming at the top of the funnel. In this respect, as in that of evaporative efficiency, the Du Temple boilers are no worse than the locomotive boilers which they have been called upon to replace on several torpedo-boats.

130. *Successive Improvements in the Du Temple Boiler.—The Du Temple-Normand Boiler.—The Guyot Boiler.*—The Du Temple boiler has been the object of numerous improvements, the enumeration of which would almost constitute a history of boilers with accelerated circulation. Some of these improvements have been introduced by the different engineers, who since 1890 have been at the head of the Du Temple establishment, but the most important are due to the makers, who successively joined the movement in favour of the new system of boilers, and in particular to M. Normand, whose improvements have since been adopted by the Du Temple firm.

Mr. Thornycroft was the first in England to apply tubulous boilers to torpedo-boats, and most probably the first to use, in the form adopted in his boiler, the method of forming screens or walls by means of tubes in contact with each other. In general arrangement the Thornycroft boiler is quite distinct from the Du Temple type. M. Normand, whose conversion to the new system largely influenced his success in France, at the outset worked in collaboration with the Du Temple firm, and the Du Temple series of boilers includes several mixed types of Du Temple-Normand boilers, before the present form, which differs very little from the Normand boiler itself, was arrived at.

As it is difficult to follow in strictly chronological order the improvements in the Du Temple boiler, only the most recent changes will be noted. One of these was the abandonment of the lower rectangular cast-iron collectors in favour of cylindrical wrought-iron ones. Independent of the fact that they were inferior in design, the rectangular collectors gave a wrong direc-

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tion to the lower ends of the tubes. These, which should be vertical at the junction of their lower ends and the collectors, in order to facilitate the settling of solid deposits in the bottom reservoirs, with the rectangular collectors, had a horizontal direction. The bottom drums are inspected by means of a single manhole in the boiler-front.

The diameters of the tubes and the forms into which they are bent have been frequently modified, but always in the direction of increased diameter and simplified form.

The boilers of the torpedo-boats Nos. 130 to 144, built in 1889, had tubes of 0·67 in. external diameter. In ten torpedo-boats, No. 145 type, tubes of variable diameters were employed, having a diameter of 0·75 in. over the lower horizontal portion, and 0·94 in. over the remaining length of the tube; the thickness was at the same time increased from 0·079 in. to 0·098 in. The diameter was made variable with the object of facilitating the escape of steam from the upper portions of the tube. In 1893 the tubes were made 0·98 in. in external diameter at the lower portion, and 1·18 ins. for the upper portion, with a uniform thickness of 0·118 in. As now made, the external diameter is uniform, and equal to 1·38 ins.

A simplified form of tube is found for the first time in the boiler of the *Chevalier*, represented by Fig. 155, where the tubes are only bent over twice instead of four times. This type, at 213 lbs. pressure per square inch, has been adopted for a good many boats, the *Lancier*, *Corsaire*, *Mousquetaire*, torpedo-boats Nos. 145, 146, 154 to 159, 170 to 181, etc.

The Du Temple establishment continued to use this form of tube, with the gases always passing across the tubes, up to 1896. In the latest boilers of this type—represented by Figs. 156 and 156A—the disadvantages inherent in this form, as regards the utilization of the heat, have been almost eliminated. The tubes rise vertically from the upper portions of the bottom drums and form a high arch over the grates, giving a good lofty furnace. A partial baffle is formed by arranging the tubes close together, causing the gases to take a transverse direction; a baffle of sheet metal, placed under the funnel, forces the gases towards the two ends of the boiler, so as to obtain about the

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same duty from the tubes near the ends as from those in the centre of the boiler. Another arrangement of generating tubes, as proposed by the Du Temple firm, may be mentioned, in which the tubes, rising from the bottom drums, cross each

BOILER OF THE CHEVALIER.

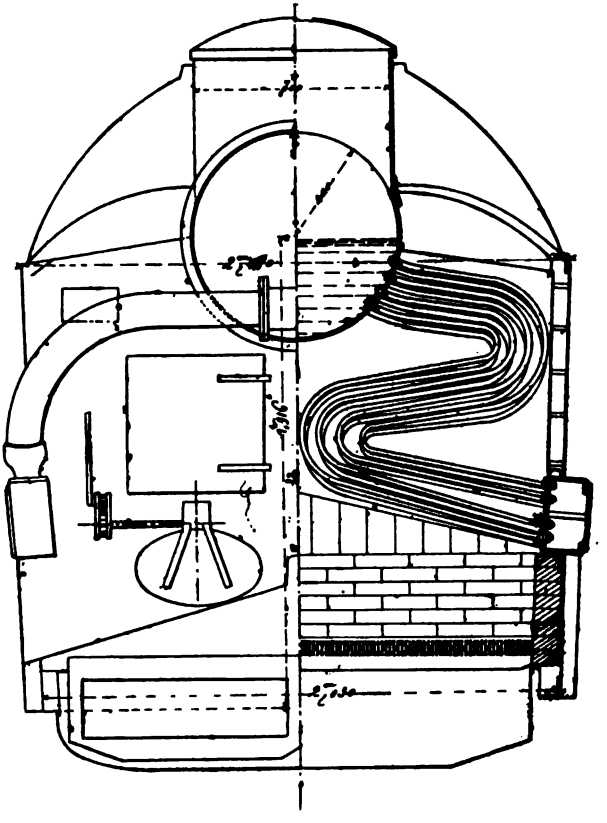

Fig. 155.

other in the centre, those rising from the right-hand bottom drum being connected to the left hand of the top drum, and those from the left-hand bottom drum to the right hand of the top drum.

At present, the Du Temple establishment are abandoning

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MANGINI.

DU TEMPLE BOILER.

Longitudinal section.

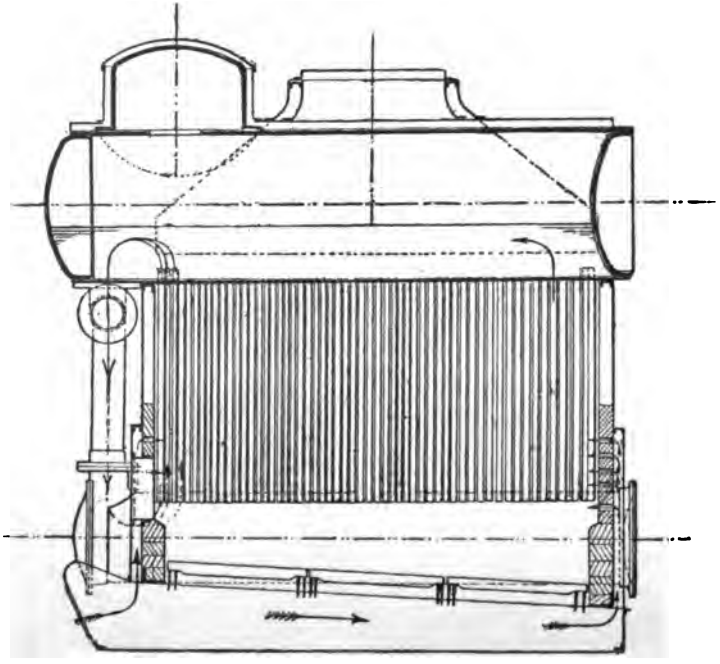

Fig. 156.

Half section. Half elevation.

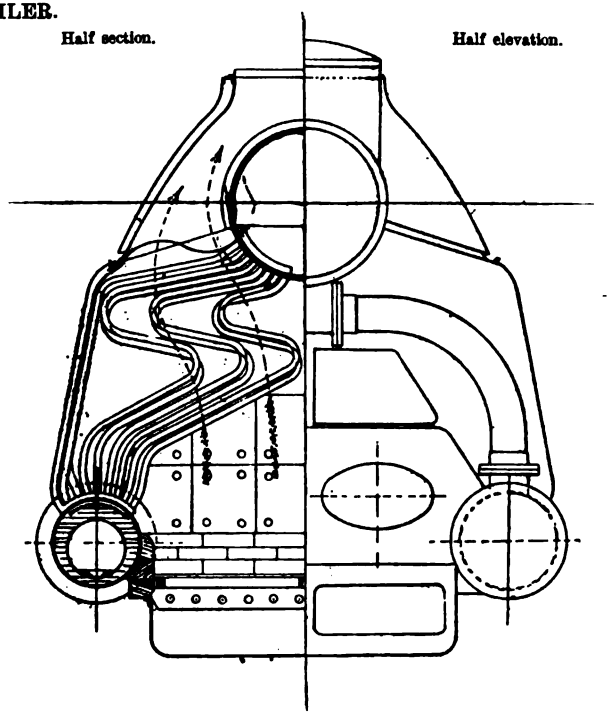

Fig. 156A.

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the use of tubes bent into several folds, with a transverse direction of the gases, in favour of the return flame type, the superior efficiency of which cannot be questioned. The tubes form a wall around the fire, and combustion is even more complete than in the furnace of a cylindrical boiler. The hot gases, returning among the banks of tubes, pass from end to end of the boiler before escaping into the funnel.

The tubes forming the closed walls or baffles, by the aid of which it is now possible to direct at will the current of gases in tubulous boilers, and even to surround the whole boiler with a water wall or jacket, are worthy of notice. It is obvious that the tubes cannot be in contact for their entire length, on account of jointing them with the reservoirs. The walls are formed by bending into the same plane the tubes of two neighbouring or contiguous rows, so arranged that the space between two of the tubes exactly corresponds to the external diameter of the tube in the other row. The short triangular spaces, which are unavoidably left at the ends of the tubes, must be closed by fire-brick or asbestos, especially at the upper ends, so as to prevent any passage of the gases. It may even be necessary to use a light backing of fire-brick or asbestos behind the tube-walls, in order to obtain the desired tightness, and, in order to completely fill any interstices which may exist between the tubes in the same plane, a small thread of asbestos is packed in between them.

The type of Du Temple boiler represented by Fig. 157 was designed by M. Guyot, an engineer at Cherbourg, and the following are the particulars of the boilers under construction at the end of 1896, and intended for torpedo-boats Nos. 206 to 211:—

Grate area	24·54 sq. ft.
Heating surface	1130·25 sq. ft.
External diameter of generating tubes	1·024 ins.
Thickness of generating tubes	0·098 in.
Weight of boiler empty, funnel and mountings included	5·71 tons.
Weight of water	1·427 tons.

The method of connecting the tube-ends to the barrels by

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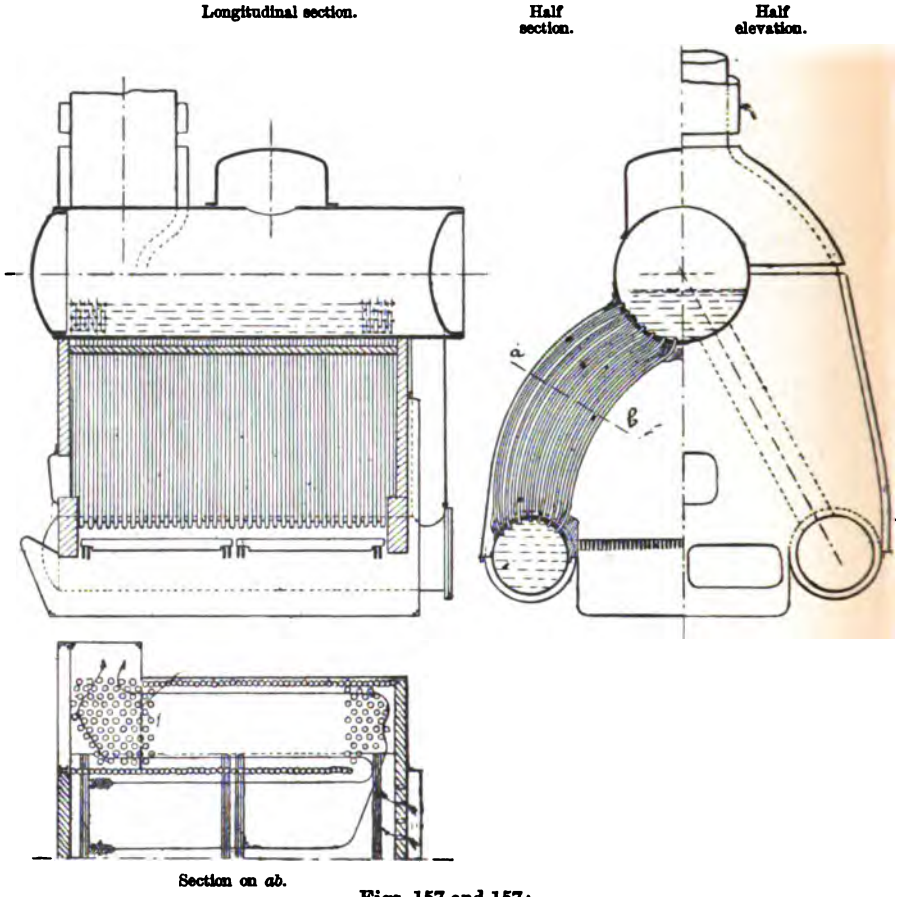
screwed joints forms a constructive detail which was adopted from the first, and is still occasionally employed by the Du Temple establishment. This joint is shown in Fig. 158, and

DU TEMPLE-GUYOT BOILER.



Figs. 157 and 157A.

consists of a cone and nut screwed on to the ends of the tubes, the plate of the barrel being gripped between them. The engineers of torpedo-boats have generally reported well of this arrangement, which facilitates replacing the tubes, and almost always permits of "plugging." Its disadvantage is an enlarge-

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ment of the holes in the barrels, and consequently the tubes have to be spaced further apart.

The cones and nuts were, until recently, of brass, but steel has now been adopted, so as to avoid galvanic action. The steel cones are screwed on to the tubes, and then fixed in position by slightly expanding the tube.

CONNECTION OF A GENERATING TUBE TO THE UPPER DRUM.

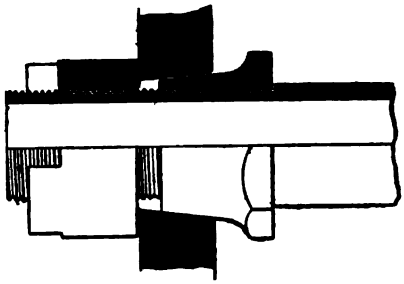

Fig. 158.

On the occasion of an accident to the upper drum of the *Chevalier*, in 1894, caused evidently by shortness of water, this form of joint proved, in a remarkable manner, its ability to withstand rough treatment. The drum was permanently enlarged (on one side only), where perforated by the tubes, in such a way as to form a longitudinal pocket, the plates being

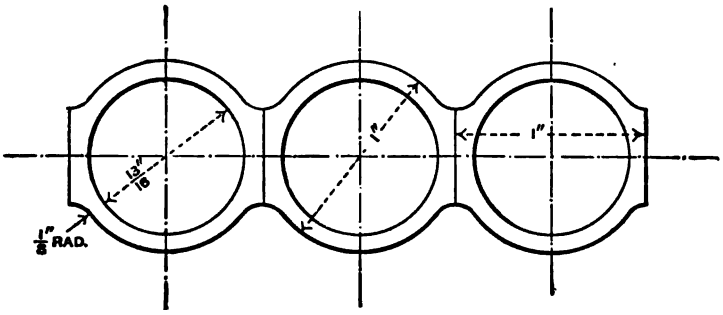

Fig. 158A.

about an inch out of the true cylindrical form. All the tube-holes became oval, with the major axis transversal to the boiler. The cones and nuts remained in place, and all the joints held well.

In some of the boilers the coned joints have been replaced by the ordinary expanded tube joints.

M. d'Aboville, manager of the Du Temple works, uses for

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the tube wall tubes specially drawn for that purpose, and illustrated in Fig. 158A. This arrangement allows the tubes to move relatively to each other without in any way impairing the tightness, and the wall has so far given complete satisfaction.

131. *Normand Boiler.*—The part taken by M. Normand in the successive improvements of the Du Temple boiler, from the time when he commenced to adopt it in place of locomotive boilers for his torpedo-boats, may be shown by comparing the two figures, 155 and 159. The latter represents the Du Temple boiler as constructed by M. Normand for the *Flibustier*, the *Ariel*, and torpedo-boats 186 and 187, and appropriately called the Du Temple-Normand boiler, from which the later types of the Du Temple boiler, Figs. 156 and 156A, are evidently derived.

M. Normand, applying to his work the methodical care and attention to detail which have gained for him such a high reputation as an engineer, designed several new and original types which retained, however, the general arrangement of the Du Temple boiler, while embodying some of the features of the Thornycroft boiler, with this important difference, that the current of hot gases has a horizontal instead of a vertical direction.

The first point to which M. Normand directed his attention was the shape or form given to the generating tubes, which he simplified by discarding the lower folds—a relic of the Sochet boiler. His tubes are only curved sufficiently to give them the required elasticity, and to bring their ends normal to the tube-plates.

In order to make the passage of the gases amongst the generating tubes of sufficient length, M. Normand gives them a longitudinal direction. With this object he designed in 1890, and 1893, two different arrangements to suit the position of the funnel (Figs. 160 and 160A).

When the funnel is towards the front of the boiler, as on the *Aquilon*, the flames pass first to the back of the furnace where they split up and return towards the front, passing

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TORPEDO-BOAT No. 186.

DU TEMPLE-NORMAND BOILER.

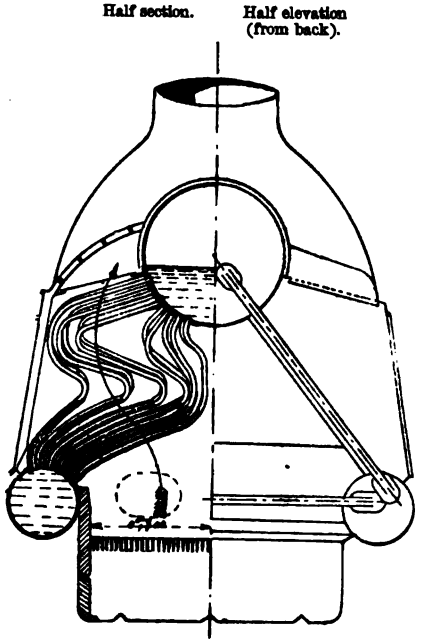

Fig. 159.

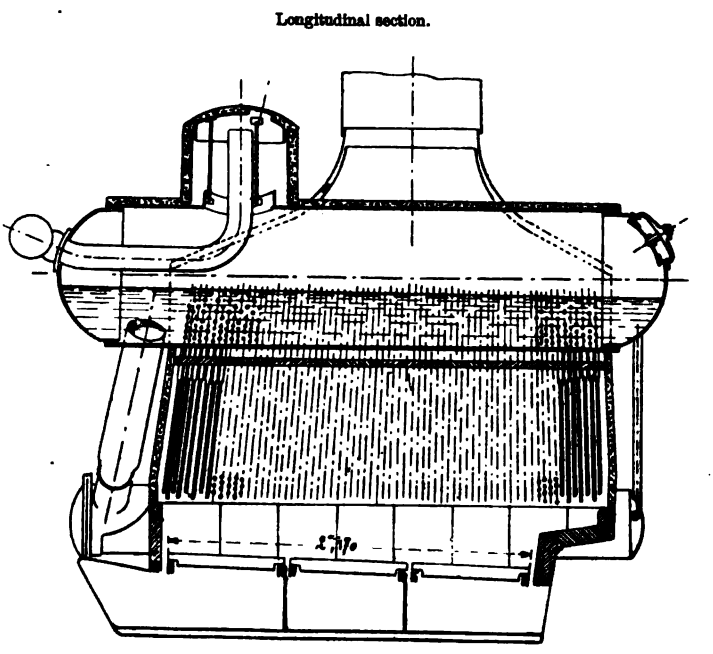

Fig. 159A.

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among the generating tubes on their way, the direction taken being thus analogous to that followed by the gases in the ordinary marine return-tube boiler. The gases escape into two smoke-boxes at the sides of the boiler. This form is known as the "return-flame" type.

When the funnel is towards the back of the boiler, as on the

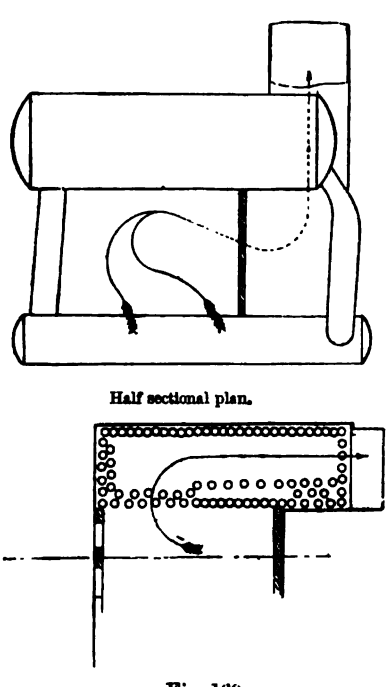

Fig. 160.

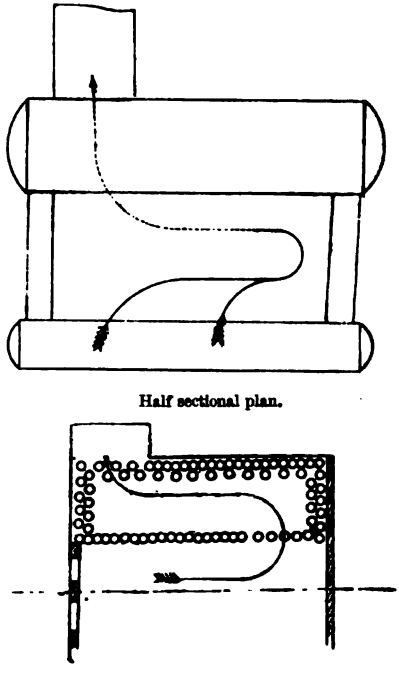

Fig. 160A.

Forban, the opening from the furnace is at the front, the back of the furnace being completely closed by a fire-brick partition; the hot gases therefore first pass towards the front, where they split up and return along the flues, formed by the generating tubes, to the back of the boiler where they escape into breeches-shaped smoke-boxes. This form of boiler, in contradistinction to the foregoing one, is known as the "direct-flame" type—a purely conventional term, as both types are in fact "return-

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flame," but the "return" is not so complete in the case of the "direct" type, and moreover its direction is reversed. The boilers are similar in other respects, except as regards the positions of the furnace and ashpit doors.

M. Normand usually prefers the "return-flame" boiler, but the selection of the most suitable type must be decided by the general arrangement of the ship.

In Fig. 161 the transverse section is applicable to both types, and the longitudinal section to the "direct-flame" type only.

The two outside rows of tubes form a tube-wall, thereby protecting the boiler casing, and forming a water-wall around the hot gases.

Some of the various arrangements adopted to direct the current of hot gases deserve notice. The two inner rows of tubes forming the tube-walls, and which constitute the side of the furnace, are so arranged as to touch each other just underneath the upper barrel, and thus form an arch or vault over the fire-grate. Fire-bricks are placed just above where the tubes approach one another to prevent the flames touching the upper drum.

The flames, before reaching the end of their passage along the bank of generating tubes, are deflected downwards by baffle plates, called by M. Normand "hanging bridges," under which they have to pass before entering the smoke-boxes, instead of escaping directly from the top. In the "direct-flame" type (Fig. 161), these baffles are placed in line with the fire-brick partition forming the back end of the furnace.

The passages in the internal tube-walls, through which the hot gases from the furnace enter the nest of tubes, are formed by leaving spaces or interstices for a portion of their height in the two rows of tubes forming the internal wall. Where these spaces are left, the tubes have sometimes been slightly reduced in diameter so as to offer less obstruction to the entry of the gases.

These details show the care taken to ensure satisfactory working and high efficiency. There are still others worthy of note. Thus, openings for the entry of air above the grate are provided both at the front and back. Those at the back are made in the brickwork forming the back or end of the furnace;

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FORBAN.

NORMAND BOILER.

Scale 22 mm. = 1 mètre.

Half section. Half elevation.

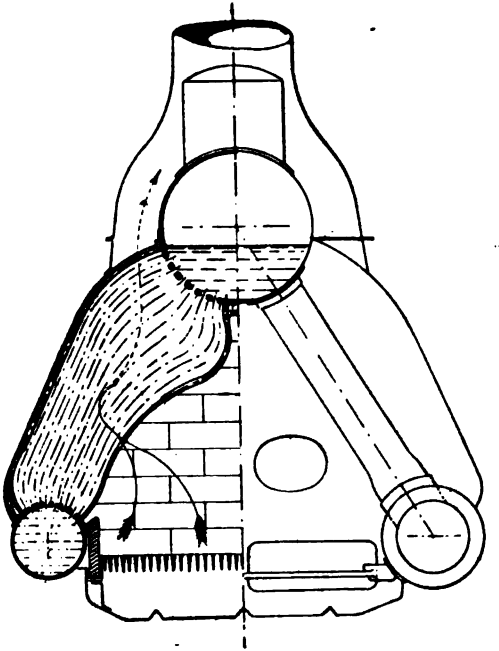

Fig. 161

Longitudinal section.

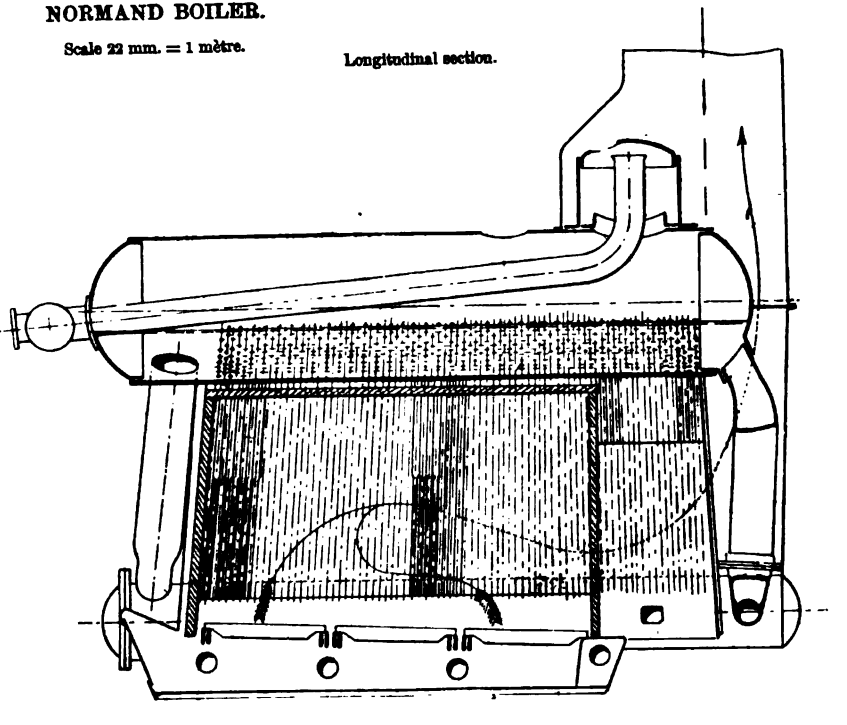

Fig. 161A.

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it is for this reason that the space at the back of the brickwork is kept clear by making the smoke-box of "breeches" shape. The air admitted at the front is first warmed by passing between the front casing of the boiler and the brickwork forming the front end of the furnace. The boiler as now constructed has been developed from the earlier types by a series of careful experiments, those made by M. Normand about the year 1894 being especially interesting.

His first boilers were fitted with brass and copper tubes with the object of increasing their durability. The three rows next the fire were of brass and the remainder of copper. These metals, however, proved unsatisfactory. Brass tubes in particular are, owing to the method of manufacture, full of small cracks which pass unnoticed when subjected to external pressure, but render the tubes unfit to stand internal pressure. M. Normand now uses only iron tubes, which he prefers to steel ones.

M. Normand at first found it difficult to provide sufficient heating surface. The great reduction in the lengths of the tubes, following the abandonment of the folds, necessitated an increase in their number, but there was not sufficient room on the top drum to accommodate their upper ends, which M. Normand considers should be below the water-level and not above, as in the Thornycroft boiler. The ends of the three outside rows of tubes were, however, above the normal water-level, but without being in any way bent downwards, so as to avoid the formation of air-pockets. He thought it necessary to protect the portions of the tubes above the water-level by a baffle plate, but this precaution is perhaps superfluous. The length of the present boilers enables a sufficient number of tubes to be used, all of which enter the upper drum below the water-level.

As a good example of M. Normand's recent boilers, those of the *Forban* may be cited, their principal particulars being as follows:—

Grate area	44·13	sq. ft.
Heating surface	2314	sq. ft.
External diameter of tubes	1·34	in.
Thickness of tubes	0·118	in.
Weight with fittings, including funnel	12·2	tons.
Weight of water	3·12	tons.

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The grate area of 44·13 sq. ft. has only been obtained by making the length 7 ft. 9 ins. Such a length renders the stoking difficult, and good stokers are necessary, although the height of the furnace facilitates throwing the coal to the back of the grate. However this may be, very good results were obtained on trial. While steaming at 31·03 knots, a rate of combustion of 63·9 lbs. of coal per square foot of grate was maintained, and 46·8 horse-power developed per square foot of grate. The results of the trials of the *Forban* are also given in Section 40, page 69, as well as those of the *Flibustier* and the *Ariel*.

132. *The Application of Normand boilers to large ships.—Normand-Sigaudy boiler.*—M. Normand having arrived by successive improvements at a type of boiler which, though not final, is undisputably superior to the original Du Temple boiler, considerable advantage should certainly be derived from its more general employment on larger ships. Single- or double-ended boilers might be used according to circumstances, the latter enabling a slight saving in weight, and space occupied, to be effected. The double-ended boiler which M. Normand has introduced in collaboration with M. Sigaudy of the Compagnie des Forges et Chantiers de la Mediterranée (Havre), is composed of two Normand boilers placed back to back, with the barrels common and continuous.

The two types—return-flame and direct-flame—form two kinds of double-ended boilers as represented by Figs. 162 and 162A, which are taken from the drawings accompanying the application for the patent. These figures are sufficiently clear, and nothing need be added to the descriptions given of the single-ended boilers. In the return-flame type (Fig. 162A), the smoke-boxes are sometimes placed on the front and sometimes on the sides according to the space available. In the direct-flame type (Fig. 162) the smoke-boxes naturally lead to a common funnel in the centre of the boiler. In both cases a clear space is left between the back ends of the furnaces for the admission of air above the grates.

The only difference due to the mode of coupling the boilers

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together is in the reduction of the downtake tubes. The direct-flame type has its downtake tubes at the ends, the return-flame has them at the centre between the two furnaces. This difference is caused by the upper reservoir of the direct-flame boiler having a reduced portion at the middle of its length, so as

NORMAND-SIGAUDY BOILERS.

DIRECT-FLAME TYPE.

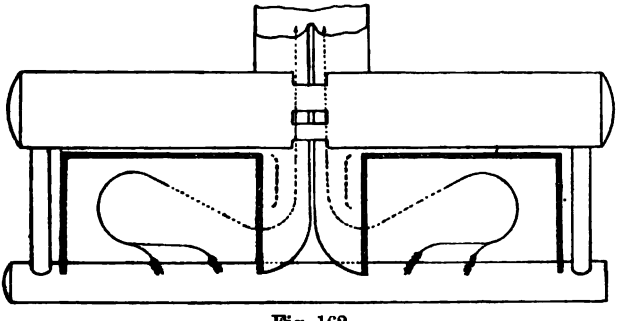

Fig. 162.

RETURN-FLAME TYPE.

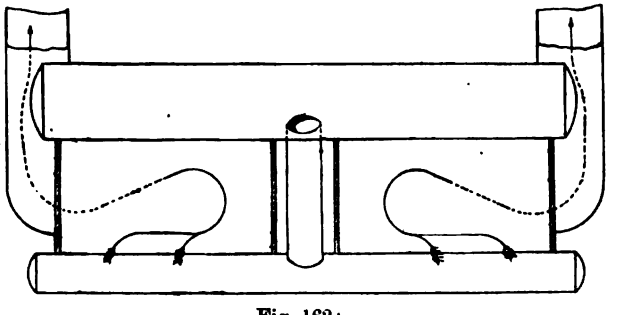

Fig. 162A.

to offer the least possible obstruction to the passage of the gases through the uptakes.

The advantages possessed by double-ended boilers are not so great in the case of tubulous as in that of cylindrical boilers, because the saving in weight is much less. On the other hand, their use presents no disadvantages; both portions of the boiler have in all cases separate uptakes, and may even be worked at different rates of forcing. Precautions should be taken to prevent excessive changes in the water-level, due to the pitching

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or rolling of the vessel, as the top drums are often over 19 feet long. Lastly, the successful application of boilers of the Du Temple class to large ships depends, as in all types of tubulous

JEANNE D'ARC.

DU TEMPLE-GUYOT BOILER PROPOSED BUT NOT FITTED.

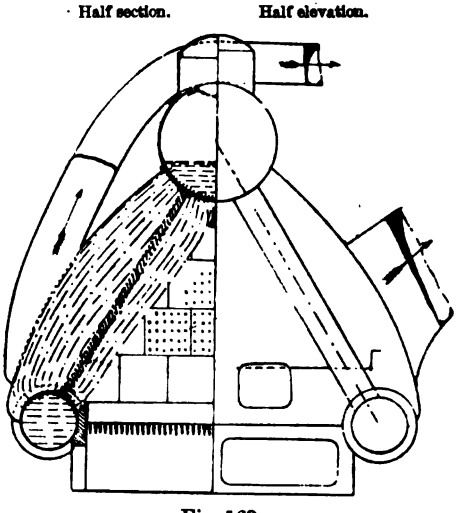

Fig. 163.

		Ratios to Grate Area.
Working pressure . . lbs. per sq. in.	242	
Number of boilers	13	
Length of grate	6 ft. 9½ ins. × 2	
Width of grate	7 ft. 5⅝ ins.	
Surface of grates . . . sq. ft.	101·16	
Outside diameter of tubes . . . in.	1·181	
Inside diameter of tubes . . . „	0·984	
Number of tubes	1,994	
Heating surface (dry) . . . sq. ft.	4,617·7	45·646
„ „ (wetted) . . „	3,859·8	38·154
Surface of water-level . . . „	60·1	0·593
Free area through ashpans . . „	18·73	0·185
Area of passages for gases between the tubes . . . . . „	28	0·296
Volume of water . . cub. ft.	117·9	0·86
„ „ steam . . . „	132	1·305
Approximate weight with grates and accessories . . . . tons.	28·9	
Total weight with water . . . „	34·7	

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boilers, on the satisfactory solution of some general problems, such as regularity of feed-supply, etc.

As examples of double-ended boilers may be mentioned those of the Du Temple-Guyot type originally adopted for the

Half longitudinal section. Fig. 163A. Half elevation.

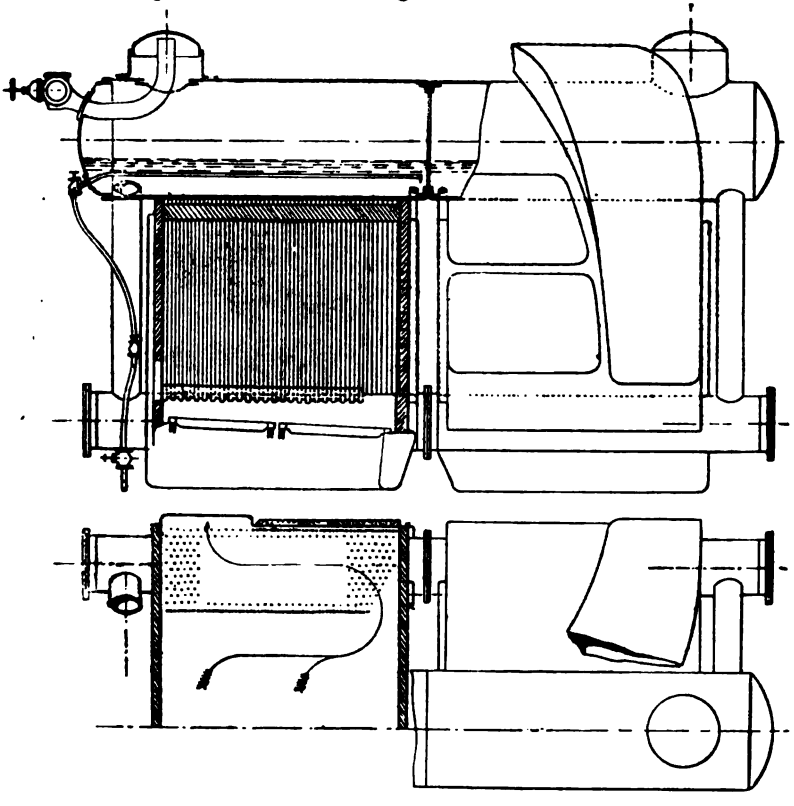

Fig. 163B.

Jeanne d'Arc at the end of 1895 and constructed at Indret, and the Normand-Sigaudy boilers adopted in 1896 for the *Chateau-Renault*, constructed at Havre, neither of which boats have as yet (1898) undergone their trial trips.

133. *Leblond and Caville Boiler.*—MM. Leblond and Caville.

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of Cherbourg, the inventors of a system of petroleum firing mentioned in an earlier portion of this work, have invented several forms of boilers, amongst them being that represented by Fig. 164, which is a type derived from the Du Temple boiler.

There is only one water-chamber, which is placed behind the fire-bridge, and an upper chamber or separator at the front of

LEBLOND AND CAVILLE BOILER, 1896 TYPE.

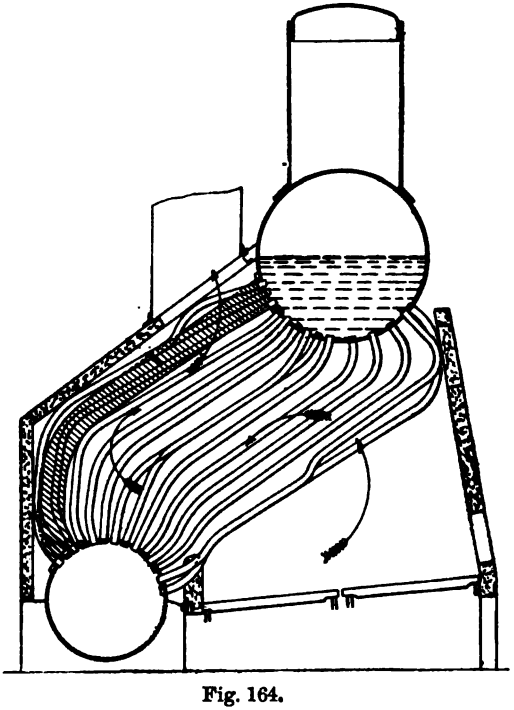

Fig. 164.

the boiler. The furnace gases, in passing among the tubes, follow the course indicated by the arrows; a tube-wall obliges them to descend before finally passing upwards towards the funnel. Circulation is provided for by means of small downtake tubes at the back of the boiler, distributed throughout its entire length —an arrangement which should render the circulation more

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complete, besides avoiding the complication of external down-take tubes.

134. *New Type of D'Allest Boiler.*—M. D'Allest designed in 1896 a new type of boiler with accelerated circulation, in which

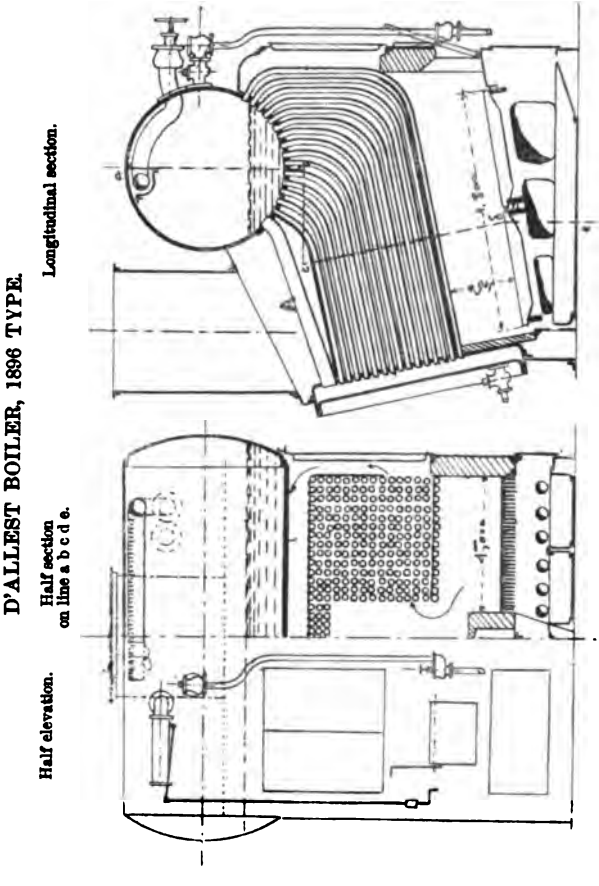

Fig. 165A.

Fig. 165.

he has preserved several of the characteristic features of his boiler with free circulation.

The water-chamber is placed behind the fire-bridge, and is of

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a flat rectangular form, of similar construction to those in the D'Allest boilers with free circulation; the generating tubes are of simple form and run from the flat-water chamber to the cylindrical top drum at the front of the boiler. The downtakes A are above the generating tubes and outside the boiler casing, and are distributed over the length of the boiler so as to assist the return of the water to the flat-water spaces. The longitudinal section of the boiler presents a remarkable likeness to that of the Leblond and Caville boiler; but the transverse section is almost the same as that of the ordinary D'Allest boiler.

There are two grates separated by a common combustion-chamber, and the gases take a course parallel with the boiler-front, the smoke boxes being at the sides.

The new type of D'Allest boiler has not yet been thoroughly tried; but its construction bears ample evidence of the experience gained by its inventor. It is of simple form and appears to be well arranged.

135. *Rapid Introduction of Boilers of the Du Temple Class.*— The almost universal adoption of tubulous boilers with accelerated circulation upon torpedo-boats followed very closely on the first success of the Du Temple boiler in France; in Germany, however, the firm of Schichau adhered for a longer time to the locomotive type.

In England, where possibly some recollection still remained of the Goldsworthy-Gurney boiler, patented in 1827 (see "Manual of Marine Engineering" by Seaton, 1895, p. 390), Mr. Thornycroft anticipated M. Normand and was followed soon after by Mr. Yarrow, and subsequently several other engineers followed in their steps. When the British Admiralty, who up till then had but a small number of torpedo-boats, decided to order a hundred torpedo-boat destroyers, the construction of this class of boilers received a great impulse, and the number of types now in service are considerable.

A complete account of the modern boiler with accelerated circulation, crediting each inventor with the part taken by him in the improvements introduced during the last ten years, would

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be as delicate and difficult a task as the history of the Belleville or the Collet-Niclausse boilers is simple and easy.

136. *Thornycroft Boiler.*—This boiler is well known in the French Navy, having been fitted to several torpedo-boats, the

THORNYCROFT BOILER.

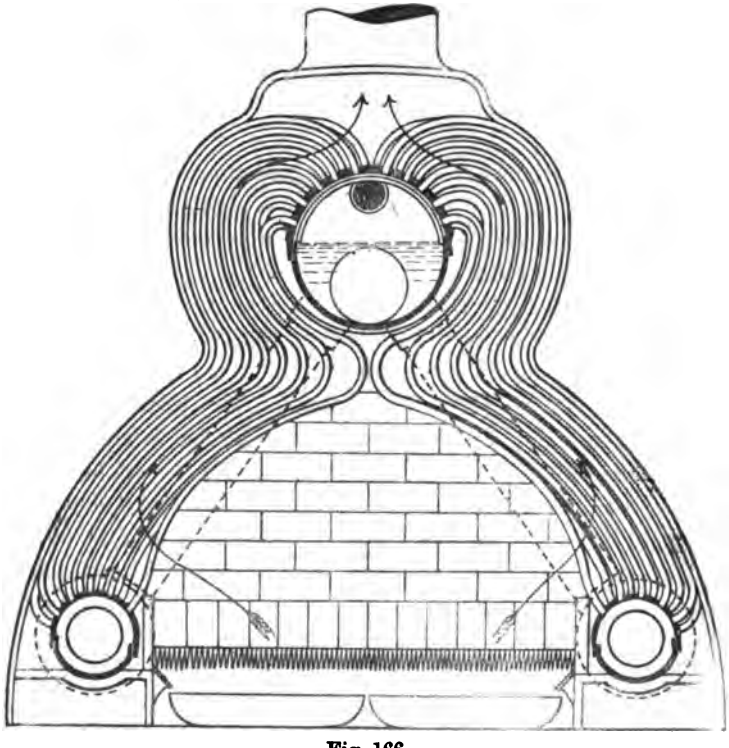

Fig. 166.

Coureur (built by Messrs. John I. Thornycroft & Co.), the *Véloce*, the *Grondeur*, and torpedo-boats Nos. 164, 165, 166.

Its characteristic feature consists in the form given to the generating tubes. These are very long; their upper ends are connected to the upper part of the steam drum or separator above the water level, and the tubes are curved in such a way as to form a complete arch over the fire-grate.

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Tube-walls are formed on the insides and outsides of each bank of tubes, leaving long triangular spaces at the bottoms of the internal, and at the tops of the external, tube walls for the free passage of the hot gases. The gases thus follow the course of the tubes throughout the whole of their length.

This arrangement gives a very large heating surface, varying from 52 to 72 times the grate area. It may be pointed out that permitting the gases to follow the direction of the tubes is not so efficient as forcing them to cross the tubes, but in adopting, and in still retaining it, Mr. Thornycroft has more particularly in view a mode of circulation which he regards as very advantageous.

From observations made with a separator provided with glass sight-holes, it appears that, with tubes delivering above the water level, the circulation, though it may be intermittent, is always in one direction.

With tubes having their upper ends submerged, the movement is, on the contrary, oscillatory, the escape of a puff of steam being followed by the entrance of water to fill the space left vacant. The result of this is that in the Thornycroft boiler there is a marked reduction in the resistance offered to the circulation, which more than compensates for the slight loss of head, equal to the height of the orifice of each tube above the water level. From approximate measurements of the velocity of the water in the downtakes Mr. Thornycroft has shown experimentally that the weight of water in circulation in his boiler is equal to 104 times the weight of that evaporated, whilst with submerged tubes it was only 50 times that weight. However this may be, there can be no doubt that the movement is, without exception, in an upward direction in all the tubes of a Thornycroft boiler, and that the water is returned entirely by the large external downtakes.

Mr. Thornycroft considers that the above-water discharge reduces the risk of priming. On this point experience has not yet enabled any exact conclusions to be arrived at. The Du Temple and Normand boilers prime but little. On the other hand the Thornycroft boilers of the *Speedy* primed during trial; but this priming was probably largely due to the bad quality of

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the water used for "make-up." The mixture of water and steam issuing from the generating tubes is projected against baffles so arranged as to prevent the water being carried along by the steam, in a somewhat similar manner to the Belleville separators.

The fear of overheating the portions of the generating tubes above the water level has given rise to some prejudice against the Thornycroft boiler. This fear is unfounded, as, while at work, there is water throughout the whole length of the tubes. In an accident on the *Coureur* the upper portions of all the tubes were melted; but there had evidently been a failure in the feed supply. This was also the case on the *Averne*, where the lower portions of the tubes of a Du Temple boiler were also burnt out. A better founded objection is the impossibility of completely filling the tubes with an alkaline solution in order to prevent internal corrosion when the boiler is laid up.

The tubes are of solid drawn steel and are merely expanded in the tube-plates. They are galvanized in order to protect them from corrosion. The zinc soon disappears in service; on the *Speedy* it was remarked that its disappearance coincided with the presence of an explosive mixture inside the empty boiler, but no satisfactory explanation of this phenomenon is yet forthcoming.

Galvanizing has the advantage of rendering very apparent the slightest defects in the steel, and thus facilitating the examination of the material; this of itself is a sufficient reason for the adoption of the process.

The lower ends of the tubes are sometimes reduced in diameter so as to cut away as little as possible the plates forming the lower barrels.

The type of boiler represented by Fig. 166 has been fitted to some vessels of moderate size, such as the *Speedy*, a boat of 800 tons, which carries eight of these boilers. Experience gained on this ship has brought into prominence the advantages of automatic feed regulators where several boilers are coupled together. Mr. Thornycroft's feed-water regulator has a counterpoise, being in this respect similar to the Belleville, but it is entirely contained inside the steam-drum, as described in Section 175.

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The leading particulars of the boilers of the *Coureur* and the *Speedy* are as follows:—

	Coureur.	*Speedy.*
Number of boilers	2	8
Total grate area . . . . sq. ft.	76·2	204
Total heating surface . . . „	4,026	14,720
Ratio of heating to grate surface . . .	52·8	72·1
Weight of boilers (dry) . . . . tons	17·37	79·7
„ „ water in boilers . . . „	3·54	12·8
Total weight. . . . . „	20·9	92·5
Total weight per sq. ft. of grate . . „	·274	·453
Total maximum power obtained on trial . .	1,507	4,500
„ „ „ „ „ per sq. ft. of grate	19·8	22·2

The greatest power developed during a run on the *Coureur* was 22·1 horse-power per square foot of grate area, with a combustion of 69·8 lbs. per square foot, and a consumption of 3·16 lbs. per horse-power. Under natural draught the *Coureur* consumes only 1·56 lbs. of coal per horse-power. On the French torpedo-boats, Nos. 164, 165, 166, the rate of combustion is not allowed to exceed 51 lbs. per square foot of grate; there is, however, nothing to show that this rate may not be exceeded without danger.

In 1892 Mr. Thornycroft devised a new form of boiler adapted for arrangement into groups on ships having several boilers. The first ships fitted with this new boiler were the two small Danish cruisers, the *Geiser*, 1,260 tons, and the *Skjold*, of 2,115 tons. They have also been fitted to the English torpedo-boat destroyers, *Daring*, *Desperate*, etc.; the third-class cruisers, *Proserpine*, *Perseus*, *Prometheus*, each of 7,000 I.H.P.; the *Barham* and *Bellona*, each of 6,000 I.H.P., and *Pomone* and *Pandora*. They have also been fitted to large boats in the Austrian and German Navies.

The following data are obtained from the official trials of recent torpedo-boat destroyers fitted with Thornycroft boilers:—

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Boat	*Daring.*	*Boxer.*	*Mallard.*	*Desperate.*	*Foam.*	*Ardent.*	*Fame.*
Duration of trial hours	3	3	3	3	3	12	12
Number of boilers . .	3	3	3	3	3	2 in use	2 in use
Tube surface sq. ft. total	8,892	9,285	12,060	12,060	12,060	6,190	8,040
Grate area sq. ft. „	189	189	196	196	196	126	84*
Indicated horse-power .	4,408	4,543	5,746	5,796	5,846	499	445
Speed . . . knots	27·7	29·17	30·2	30·03	30·1	13	1·27
Indicated horse-power per sq. ft. of grate .	23·3	24	29·3	29·6	29·8	3·96	5·3
Indicated horse-power per ton of boilers complete with all mountings and fittings and including water . .	96½	97	99⅜	107½	106		
Coal per horse-power per hour . . lbs.	..	..	2·08	..	2·205	1·53	1·66

* Length of grates reduced for this trial.

Mr. Thornycroft's boiler for grouping on large vessels is shown in Fig. 167; each group is composed of separate and distinct elements contained in a common casing. Each element includes two drums only, placed vertically one over the other, and connected by two banks of generating-tubes. The down-takes are distributed over the length of the boiler in the space between the two sets of generating-tubes, an arrangement which permits of an excellent circulation.

In this design each element is heated by two furnaces, and each furnace serves for two half elements. The grates at the ends of the group (which only serve one half element) are smaller than the rest, and the outside of the furnace is formed by a tube-wall, the tubes of which are connected at their lower ends to a small barrel or wing-tube.

This arrangement for grouping the *Daring* type of boiler shows an economy of weight over the *Speedy* type.

The disadvantages of a boiler of several elements are that in case of accident to one of the elements, such as the bursting of a tube, the whole group is filled with steam, all the furnaces being in communication. It would then, presumably, be necessary to draw the whole of the fires in the group in order to replace the defective tube—an operation at times of rather long duration.

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The boilers of the *Daring* consist of three groups of the type shown in Fig. 167, and have a total grate area of 189 sq. ft. The heating surface is forty-two times the grate area. On a full-speed trial, when 29·268 knots were recorded, the air-pressure in the stokeholds was 3·15 in. and the horse-power 23·5 per sq. ft. of grate. The boilers were found to work satisfactorily.

The *Desperate*, which has likewise three boilers, has attained

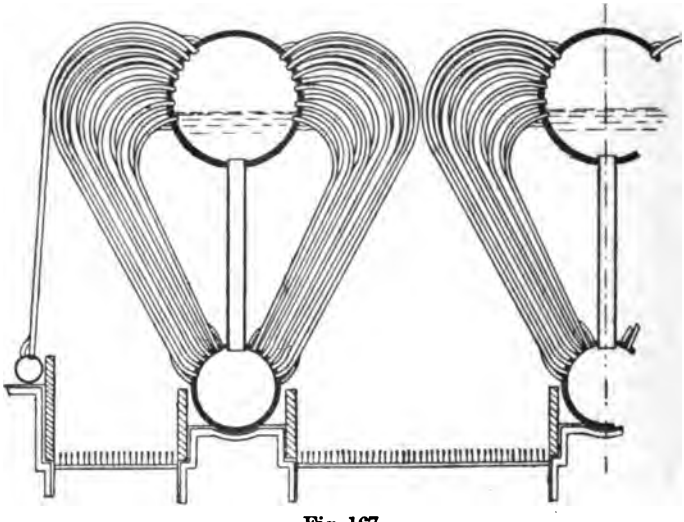

Fig. 167.

a speed of 30·006 knots, while developing 5,800 horse-power. At this rate of forcing, the consumption of coal per horse-power was 2·48 lbs.

137. *Mosher and Symon-House Boilers.*—Up to the present only two engineers have followed the example of Mr. Thornycroft in arranging the generating-tubes so as to discharge above the water-level. The Mosher boiler, of American origin, is represented by Fig. 168, and somewhat resembles the *Daring* type, but with this difference, that there is one grate for two elements instead of two grates for one element. In case of accident to one of the elements the other can be kept at work, but at the expense of burning the tubes of the first; this is a point of some importance in boats having only one boiler.

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The ends of the furnace are formed by a tube-wall, as seen in the figure.

The Mosher boiler has been fitted to several yachts and to the second-class torpedo-boat carried by the ill-fated battleship *Maine*. At the Chicago conference the inventor gave the

MOSHER BOILER.

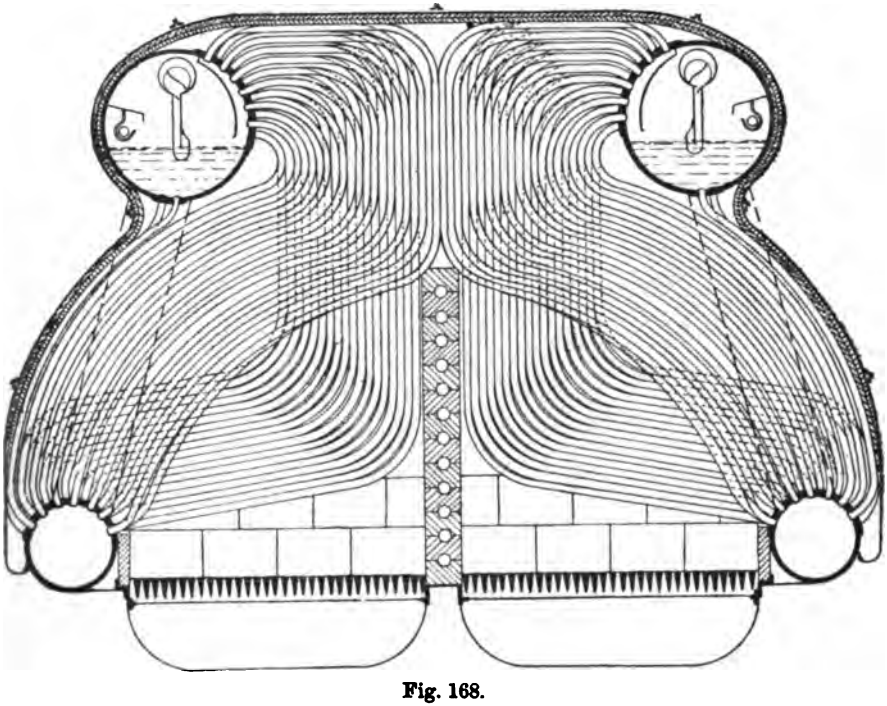

Fig. 168.

following as the result of an eight-hours natural draught trial, burning Pocahontas semi-bituminous coal.

Coal per square foot of grate per hour	7·1 lbs.
Water evaporated per lb. of coal	9·12 „
Air supplied per lb. of coal	304 cub. ft.
Temperature of gases at base of funnel	442° Fahr.
Draught at base of funnel	3 in.
Wetness of steam as measured by calorimeter	1·5 per cent.
Percentage of ashes	7 „
Quantity of water evaporated in the ashpans during the whole trial	99·2 lbs.

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The principal dimensions of the boiler were:—

Grate area	33 sq. ft.
Heating surface	1,108 „
Ratio of grate to heating surface	33·6
Load on safety valves	185 lbs. per sq. in.

Particulars of the heat losses in this boiler have previously been given. (See p. 121.)

SYMON-HOUSE BOILER.

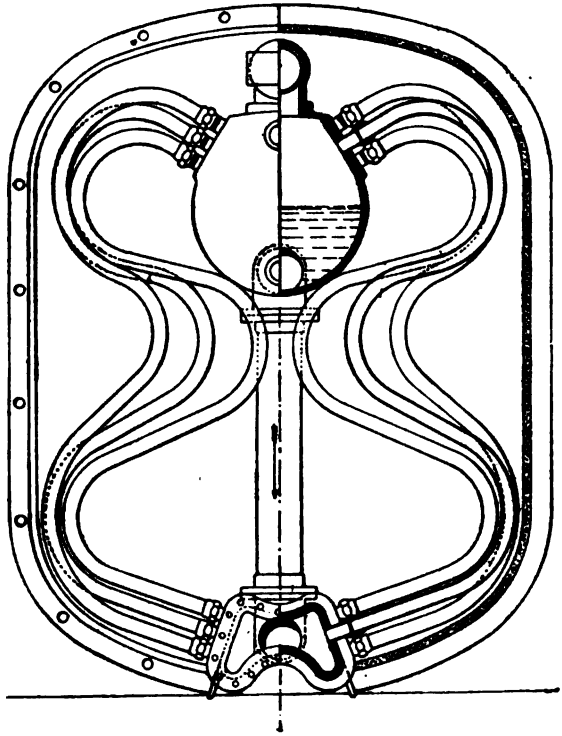

Fig. 169.

The Symon-House boiler, which is specially intended for use with petroleum fuel on small boats and launches, is very similar to one of the elements of a *Daring* type boiler, with the furnace placed between the two banks of tubes instead of being outside. The flames pass three times over the tubes, which are bent to a double S shape. The particular form given to the

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bottom reservoir, shown in Fig. 169, is for the purpose of accommodating the propeller shaft, the engine being forward of the boiler.

The tubes are of copper and are attached to the reservoir through the medium of Delta metal nipples screwed into the walls of the latter, as shown in Fig. 170.

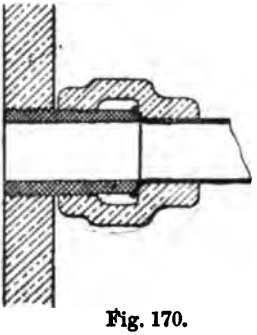

Fig. 170.

The joint faces are conical and held tight by a nut. Owing to this form of connection the tubes can be very quickly attached or detached; the shape of the bottom chamber would make it difficult to use the ordinary expanded joint.

The weight of a Symon-House boiler suitable for a 20 horse-power engine, is—

Without water or mountings	238 lbs.
Without water, but with mountings . . .	300 „
With water and mountings	337 „

being an average weight of 18 lbs. per horse-power.

138. *Yarrow Boiler.*—Amongst the numerous types of recent origin, the Yarrow boiler is possessed of characteristics no less original than those of the Thornycroft, but of quite a different nature. Its chief characteristic is its extreme simplicity and lightness.

Fig. 171 represents the boiler of a small torpedo-boat ordered by the French Navy for the *Foudre*. The tubes are all in a straight line from one chamber to the other; their lower ends are expanded into a thick flat plate, and their upper ends into a cylindrical barrel, the plates of which are increased in thickness where perforated by the tube holes, so as to allow of the tubes being well expanded. The three chambers are each in two parts with external flanged and bolted joints. Access to the whole of the tube ends is at once obtained on removing the outer segments. The tubes can be cleaned and examined

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internally with the greatest facility; in an emergency Mr. Yarrow effected the replacement of a tube in forty minutes.

In large boilers upper barrels with bolted joints could not

YARROW BOILER OF ALUMINIUM TORPEDO-BOAT C.

Scale $\frac{1}{10}$.

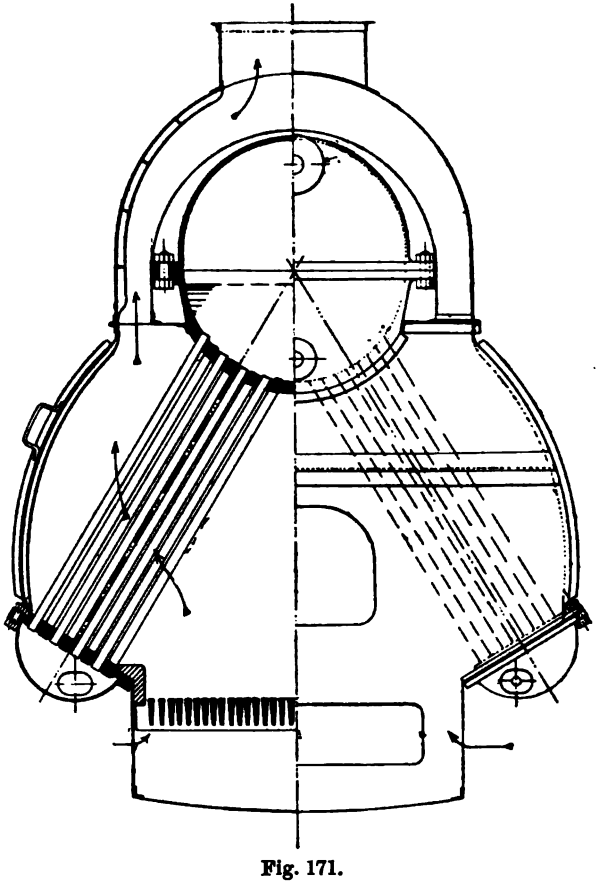

Fig. 171.

be constructed capable of supporting the pressure, and so they are made with the usual riveted joints, and in consequence lose the advantages possessed by the divided barrels; but this is not of much importance as their large size permits of ready access for the examination and replacing of the tubes.

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The straight form of the tubes greatly reduces the number of "spares" required and facilitates the replacing of a tube afloat.

Another simplification adopted by Mr. Yarrow is the abandonment of large external downtakes. The circulation takes place entirely in the banks of generating tubes, a feature which places the Yarrow boiler somewhat behind the group of those with accelerated circulation, in spite of its evident analogy to the Du Temple and similar types of boiler. Mr. Yarrow was led to this arrangement by the results of the curious experiments upon the circulation of water, explained in Sections 124 and 125. He demonstrated that when getting up steam the water in certain tubes would ascend while in others it would descend, and that the circulation thus started would be maintained in the same direction in a permanent manner by reason of the laws of distribution of temperature in a heated circuit, and that therefore downtakes were unnecessary. It should be noted that the observations made by Mr. Yarrow, and the conclusions drawn therefrom, are only applicable to straight tubes offering but slight resistance to the movement of their contents.

Mr. Yarrow has tried tubes of various materials. At first he used steel ones. Afterwards he adopted brass tubes at a time when they were being almost universally abandoned. He expressed satisfaction with this change at the commencement of 1894, because he had been able to obtain brass tubes of a special make free from the fine cracks mentioned on page 309. Since then he has returned to steel, possibly on account of the changes in the elastic qualities of copper alloys at high temperatures, or perhaps simply owing to the difference in cost.

The great defect of the Yarrow boiler is the want of flexibility in the tubes, which necessarily tends to start the joints in case of unequal expansion. Mr. Yarrow states, however, that the joints, when properly expanded into plates of increased thickness, never show the slightest leakage.

One of the eight boilers of the *Hornet* was submitted to the following severe tests before being placed on board. Pressure

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was got up in twenty-two minutes by forcing the draught to a pressure of 3½ in. of water; the boiler was then worked for thirty-eight minutes, when the fires were suddenly drawn, the fire and ashpit doors being at the same time thrown open to the cold air. No trace of injury was observable. This test was severe, but the cooling effects were the same on all the tubes simultaneously. A more convincing fact is the extended adoption of the Yarrow boiler on the new English torpedo-boat destroyers. Besides the *Hornet*, this boiler has been adopted for the *Salmon* and the *Snapper*, by Earle's Ship-building Company, Hull; the *Hardy* and *Haughty*, by Messrs. Doxford, Sunderland; the *Opossum*, *Ranger*, and *Sunfish*, by Messrs. Hawthorn, Leslie, and Company, Newcastle-on-Tyne; and the *Spitfire* and *Swordfish*, built by Messrs. Armstrong, Mitchell, and Company at Elswick.

The principal experience hitherto gained has been with the *Hornet*, where the Yarrow boilers were in competition with the locomotive boilers of the *Havock*. The principal dimensions of the *Hornet's* boilers, which might be compared with those of the *Speedy* previously given, are as follows:—

Number of boilers	8
Total grate area	164·8 sq. ft.
Total heating surface	8,216 „
Ratio of grate to heating surface	49·8 „
Total weight (water included)	43·1 tons.
„ „ „ „ per square foot of grate area	0·262 ton.

In completing the comparison with the Thornycroft boilers it should be noted that if the heating surface is relatively less on the *Hornet* than on the *Speedy*, it is on the contrary greater than on the *Daring*; on the other hand, the advantage of lightness is certainly less when compared with the *Daring* than with the *Speedy*.

After the Thornycroft and Yarrow boilers we will notice briefly the other English types of more recent origin.

139. *Blechynden Boiler.*—In the boiler constructed by Mr. Blechynden of Barrow-in-Furness, the same facilities for with-

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drawing and replacing the tubes as are obtained in the Yarrow boiler with the upper drum in halves are secured, while permitting the use of a completely riveted upper chamber. All the tubes are slightly curved to arcs of different radii which converge to the same point on the plates of the drum. At

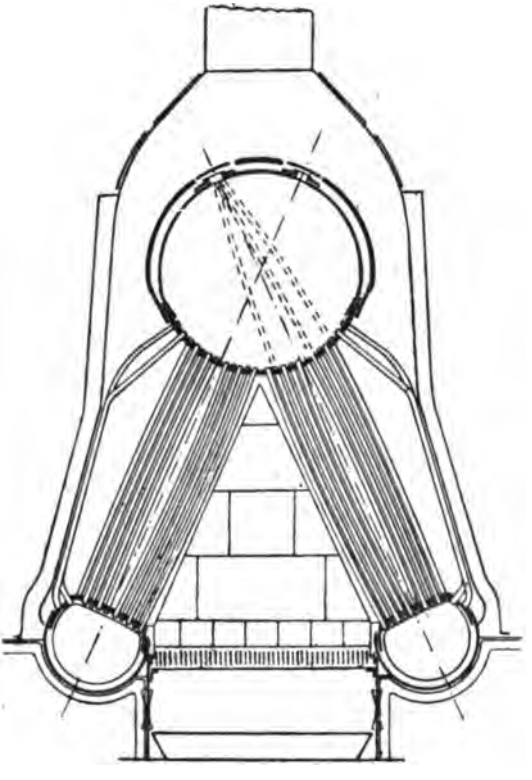

Fig. 172.

this point hand-holes are arranged along the length of the boiler sufficiently close together to allow of the introduction or withdrawal of any of the tubes, each one of which can thus be removed independently of the others.

As in the Yarrow boiler, to which on the whole the Blechynden bears a striking analogy, there are no external downtakes, the water being supposed to descend by the two outside rows of

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tubes, which form a tube-wall for the protection of the casing, and which are besides somewhat removed from the banks of tubes.

Three Blechynden boilers have been ordered by the Admiralty for first-class torpedo-boats. This type has also been adopted for the *Sturgeon*, the *Skate*, and the *Starfish*, built by the Naval Construction and Armaments Company of Barrow, as well as for the two cruisers *Pactolus* and *Pomone* of the *Pelorus* class, the machinery for which was supplied by Messrs. Penn.

The working pressure of the most recent Blechynden boilers is 300 lbs. per square inch for a pressure of 250 lbs. at the engines; this large drop in pressure necessitates the employment of a reducing valve.

140. *Reed Boiler.*—The Reed boiler (Fig. 173) amongst all the English types is the one which most nearly resembles the Du Temple, having a transversal movement of the hot gases, and tubes discharging below the water level in the upper drum; the tubes are bent in a manner recalling the zigzags of the Sochet boiler. The inside row of tubes is bent into a wavy form, which is, however, somewhat unfavourable to the free escape of steam.

Another analogy to the Du Temple boiler consists in the use of screwed tube connections (Fig. 174), only the joint, instead of being made upon a conical face and a plane face, is made upon two spherical faces, which allows of a certain angular "play" of the tubes.

Reed boilers have been adopted for several English torpedo-boat destroyers, the *Janus*, the *Lightning*, the *Porcupine*, and the *Star*. In a coal-consumption trial on land, under natural draught, they have evaporated 12 lbs. of water per lb. of coal from and at 212°.

141. *White Boiler.*—Mr. Samuel White, of East Cowes, has adopted a type of boiler which might be contrasted with the Yarrow were it desired to contrast the two most extreme cases of complexity and simplicity in similar boilers.

The tubes joining the three chambers are of two kinds, one being large and of simple form, the other, small and bent into

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spirals. The large tubes, bent into a simple Z form and reduced at the ends so as not to cut away too much of the barrel plates, form two partitions, which divide the interior of the flame space into three parts.

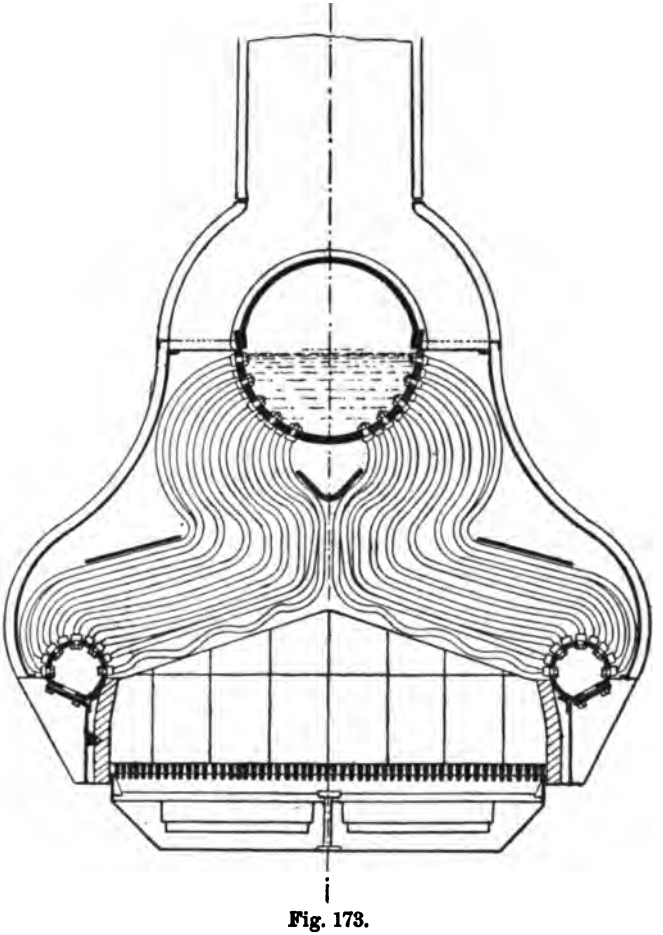

Fig. 173.

The flames rise vertically in the central portion, and return towards the funnel by the outside portions. The small tubes form seven rows of spirals, of which five are in the centre and one in each outside portion of the boiler.

The front and back ends of the boiler are protected on the

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inside by large tubes arranged close together, as shown to the right of Fig. 175. White's boiler has been adopted by the English Admiralty for some first-class torpedo-boats.

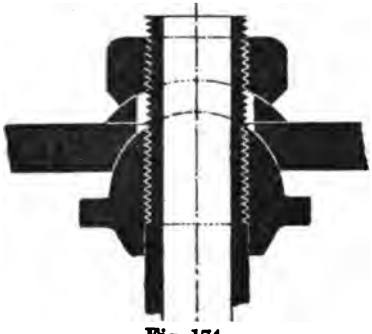

Fig. 174.

142. *Fleming and Fergusson Boiler.*—This type (Fig. 176) has been specially introduced for use in the merchant service, where questions of maintenance, repairs, and renewal become of vital importance, and where there is not sufficient room around the boilers for withdrawing and replacing the tubes of boilers of the Blechynden type. In order to perform this operation within the limits of the boiler itself, the lengths of the tubes have been reduced and the diameter of the upper drum increased until the tubes can be wholly withdrawn into it.

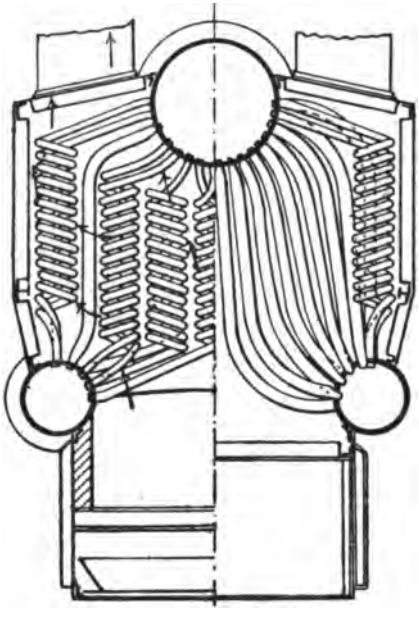

Fig. 175.

On account of its large diameter, an upper drum can accommodate more than two banks of tubes. The inventors have designed several types of boilers, some with the grates running longitudinally, others transversely, some of the boilers being single-ended and some double-ended, while one upper drum is sometimes in connection with two, sometimes three or even four lower drums.

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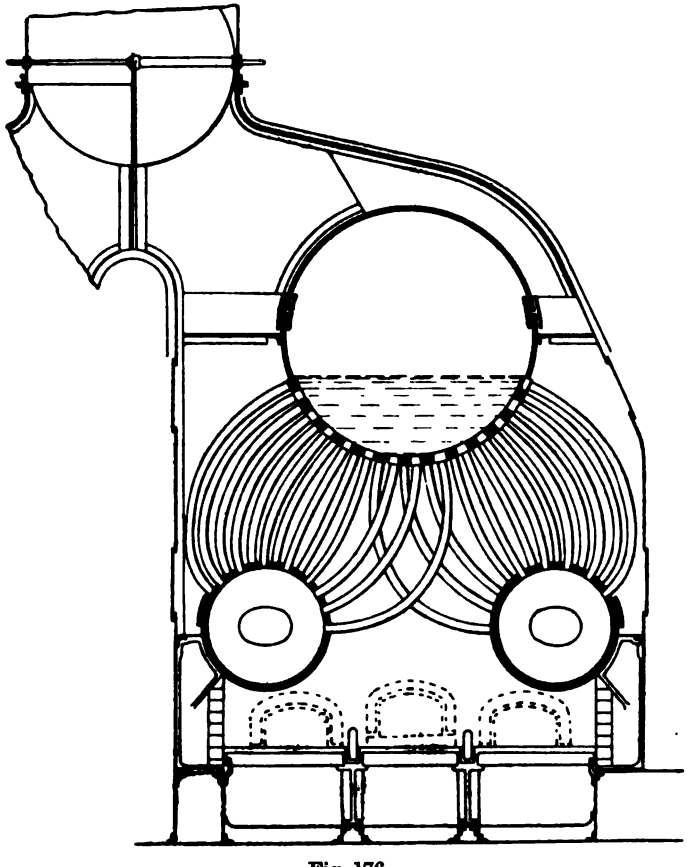

Fig. 176.

—	Boiler with 3 Furnaces (Fig. 176).	Boiler with 6 Furnaces (double-ended).	Boiler with 4 Transverse Furnaces.
Grate area . . . . . sq. ft.	50	138	165
Heating surface . . . . . „	1,450·5	4,801	5,000
Ratio of heating surface to grate . .	28·98	34·79	30·3
Total weight with water, but without funnel . . . . . tons	30	75	110
Working pressure . lbs. per sq. in.	220	200	250

A feature common to all the types is the increased spacing of some of the tubes at their upper ends so as to allow of the

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crossing of corresponding tubes in both banks, as shown in Fig. 176.

The weight, at least equal to 0·685 ton per square foot of grate area, is not below that of locomotive type boilers, therefore the adoption of the Fleming and Fergusson boiler would be determined by superiority in working and not by economy in weight.

143. *Seaton Boiler* (2nd type).—The length of the tubes being the principal obstacle to their renewal, Mr. A. E. Seaton, of Hull, has designed a boiler in which they are divided into two portions by an intermediate reservoir, into which they can be withdrawn. The Seaton boiler (Fig. 177) has the form of an X. There are two upper and two lower barrels at the extremities of the branches, the intermediate one being at their intersection.

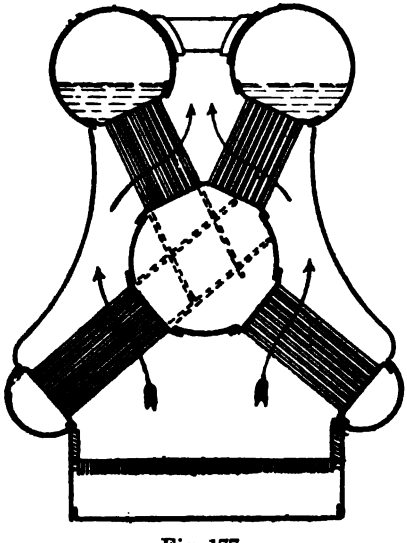

Fig. 177.

The hot gases pass successively across two banks of tubes, playing around the intermediate reservoir on their way, and escape into the funnel by the space between the two upper barrels.

The usual external downtakes connect the two upper drums directly with the lower ones. On each side is a tube wall for the protection of the casing. The tubes of this wall are directly connected with the lower and upper barrels; these tubes, which are, however, less exposed to heat than the others, do not present the same facilities for removal as those in the principal groups. The two upper barrels are joined together by transverse tubes.

The Seaton boiler appears to fulfil, in a very complete

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manner, all the practical requirements of a good marine boiler, as regards maintenance and repairs. The presence of the intermediate reservoir full of water must, however, result in a substantial increase of weight.

144. *Various Types.*—The long enumeration we have just made is still incomplete. At present there exist several other types of tubulous boilers which have been applied to marine purposes. The Roberts, an American boiler, which recalls the first type of the Du Temple with its zigzags, is in use on a yacht. The Petersen boiler, constructed by Mr. Fraser, of Millwall, has the upper and lower drums connected by elements or groups containing 16 or 17 tubes. There are thus 88 elements only for 1,476 tubes. The first trials made on land appear to have given satisfaction. Many original designs are being tried, notably the Solignac boiler, of which there are several interesting types, which the inventor intends trying on board ship. The quantity of water, which is very small, becomes completely evaporated and is controlled by a system of valves. The arrangement of the generating tubes, which at first resembled that in the Du Temple, at present more nearly recalls that of the Joessel-D'Allest boiler.

In general, the majority of new designs are on the lines of the Du Temple boiler, more or less modified.

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CHAPTER XIV.

ADVANTAGES AND DISADVANTAGES OF TUBULOUS BOILERS.—COMPARISON OF THE DIFFERENT TYPES.

§ 1. GENERAL ADVANTAGES OF TUBULOUS BOILERS.

145. *General Advantages and Special Adaptability to Naval Purposes.*—Some of the advantages of tubulous boilers are equally apparent whether for land or marine purposes, and should justify their being more generally adopted on shore than is at present the case. Other advantages are more particularly appreciated afloat, and account for their extended adoption on board ship.

In this chapter the general advantages of tubulous boilers will be first considered, and afterwards their special adaptability to marine purposes, with which this treatise is alone concerned.

146. *Ability to stand High Pressures.*—Tubulous boilers are particularly adapted to support very high pressures, because the majority of them, particularly all those having limited or accelerated circulation, are composed almost exclusively of cylindrical elements of small diameter, the pressure in all cases being internal.

In the ordinary cylindrical tubular boilers a maximum pressure is soon reached, which, for the shells, is strictly limited by the thickness of shell-plates obtainable, and for the furnaces, by difficulties in construction, not yet overcome, and perhaps even insurmountable. With tubulous boilers, on the contrary,

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no limit of pressure is imposed, except by considerations affecting the working of the engines, and this is solely one of temperature, which may disappear as methods of lubrication are improved.

Tubulous boilers are now commonly constructed for a working pressure of 300 lbs. per square inch, a reducing valve supplying steam to the engines at a pressure of 260 lbs. per square inch. Finality has evidently not yet been reached in this direction.

147. *Comparative Immunity from Accidents.*—The comparative immunity from accidents depends partly upon the ability to support very much higher pressures than the working pressure of the boiler, and partly on the small volume of water and steam contained. Except in their immediate neighbourhood, tubulous boilers are a far less source of danger to surrounding buildings than cylindrical or tubular boilers, as the effect of an explosion is felt over a very much more limited area.

It is no longer possible to speak of immunity for the stokehold staff on board ship since the catastrophes on the *Sarrazin* and *Jauréguiberry*, which were caused by tubulous boilers. Some types, however, have undoubted advantages in this direction. The Belleville boilers, for instance, which have given rise to trifling accidents and caused a good number of scaldings, have not to the author's knowledge been the cause of any accidents attended by fatal results. On torpedo-boats the Du Temple and Thornycroft boilers, for instance, have had the inner rows of tubes next the furnace severely burnt, but without any injury to the stokers. These accidents cannot be compared in seriousness to those caused by similar shortness of water in boilers of the locomotive type.

Given a judicious selection of type, and the necessary care in working, the adoption of tubulous boilers should be attended by a marked diminution in the occurrence of really serious accidents.

Amongst the properties of tubulous boilers tending to prevent accidents may be mentioned the increased durability of the various component parts when subjected to rapid changes of temperature. This point is again referred to in Section 154.

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§ 2. SPECIAL ADVANTAGES FOR MARINE PURPOSES.

148. *Lightness of Tubulous Boilers. — Consideration of Weight.*—The principal advantage of tubulous boilers for marine purposes over tubular boilers, and the motive dominating their adoption, and justifying the boldness displayed in their introduction, is their great lightness.

The detailed tables of weights given in Sections 95 and 160 permit of minute comparisons being made between the weights of the various types of boilers, and also between the weights of the several component parts on which the differences principally rest.

In arriving at a comparison between the various types, the Official figures given in the Returns will not alone be relied on, but the mean results obtained from statistics of a large number of engines and boilers as supplied by their makers will also be made use of.

The weights found in these statistics differ a little from those taken from the Official Returns and embodied in the Tables in Sections 95 and 160, as the latter were taken after the boats had been delivered to the arsenals.

The quantity of water contained alone accounts for more than one-third of the saving in weight realised, and varies greatly with the different types of boiler.

The Admiralty type of cylindrical boiler contains 10·66 cub. ft. of water per square foot of grate, and the return tube, or Scotch boiler, 7·38 cub. ft., giving a mean of 9·02 cub. ft. for cylindrical boilers.

In locomotive boilers the mean is as low as 4·92 cub. ft., varying between 4·26 and 5·58. Turning to tubulous boilers, the Belleville has only 0·885 cub. ft., the Niclausse 2·07, and the D'Allest type 2·69 cub. ft.

Boilers with accelerated circulation had at first a weight of water equal to that of the Belleville boiler, but it has gradually risen until it has reached that of the D'Allest boiler. The reduction realised in weight of water, however, is more than 0·183 ton per square foot of grate.

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The following gives the total weight per square foot of grate:—

Cylindrical boilers, Admiralty type	1·124 tons.
Single-ended cylindrical marine boilers	0·85 „
Double-ended marine boilers	0·814 „
Locomotive boilers for ships	0·96 „
„ „ torpedo-boats	0·549 „
Belleville boiler	0·53 „
D'Allest boiler	0·539 „
Niclausse boiler	0·466 „
Du Temple boiler (old type)	0·329 „
„ „ (present)	0·411 „
Normand boiler (present)	0·421 „
Thornycroft boiler (old type)	0·356 „
„ „ of H.M.S. *Speedy*	0·453 „

The weight per square foot of fire-grate of modern tubulous boilers considered suitable for use on large ships is very nearly half that of the ordinary return tube cylindrical boilers. The weight of the lightest class of tubulous boilers is about one-third those of Admiralty cylindrical type, that is to say, merely equal to the weight of water contained in these latter.

Boilers with accelerated circulation, suitable for use on large ships, will not apparently be any lighter than the Belleville and Niclausse boilers.

In the preceding Table only the weights of boilers for warships have been given. In the merchant service, according to the figures given for two transatlantic liners in the Table, Section 95, the weights amount to 1·27 tons per square foot of grate.

The adoption of Belleville boilers by the Messageries Maritimes has, therefore, reduced the weight of the boilers 40 per cent.

The weight per square foot of grate would represent the relative weights of different boilers if the evaporative power per square foot of grate were the same for all. This is very far from being the case, especially in the navy, where forced draught is almost universally used. The relative weights of boilers can thus only be determined after very careful examination, which in the nature of the case must be incomplete, as it is

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impossible to determine with any exactness the maximum evaporative power of a boiler.

The real coefficient of lightness, the weight per horse-power, is equal to the weight per square foot of grate surface divided by the maximum horse-power per square foot of grate surface, always supposing the weight of steam per horse-power required by the engines to be a constant quantity.

The relative weights can only be determined by the ability of the various types of stand forcing.

149. *Ability to Stand Forced Draught.*—From this point of view tubulous boilers may be divided into two very distinct groups.

Firstly, types with limited and free circulation, especially constructed for regular working at a moderate air pressure. In these the steam does not get away with great freedom; the passage of the flame among the tubes is short and the volume of the combustion-chamber is, as a rule, small. The maximum horse-power developed afloat up to the present time has been, in the Belleville and the Niclausse boilers, from 12 to 13 horse-power per square foot of grate, and 16 horse-power in the D'Allest boilers of the *Cassini*. These boilers have the advantage of a large combustion chamber, qualified, however, by the inability of the generating tubes to stand hard forcing. On board torpedo-boats, the Oriolle boilers have been pushed to 22·9 horse-power per square foot of grate, but the production of smoke at that power became excessive. All these boilers appear to be made, in actual working conditions, for an output of about 14 horse-power per square foot of grate.

Secondly, boilers with accelerated circulation, constructed specially for torpedo-boats, and afterwards applied to other vessels, and capable of working at high rates of forcing. In these the steam can get away with great freedom; the flame passages are generally long, the furnace is usually high, and they are sometimes fitted with a small lateral combustion chamber for the return of the hot gases.

The latest types of the Du Temple and the Normand boilers

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have given, without inconvenience, up to 37 and 41 horse-power per square foot of grate.

In comparing cylindrical boilers, giving about 18 horse-power per square foot of grate surface, and locomotive, giving 32 horse-power, with the tubulous type, we find that tubulous boilers with limited and free circulation are inferior as regards combustion to tubular boilers, but that tubulous boilers with accelerated circulation are superior to them.

At the rates of working above referred to, tubulous boilers of both groups have, without exception, the advantage that they distress their principal elements very much less than cylindrical boilers. Their tube joints are more easily kept cool and much less subjected to the action of heat, and there are no furnaces to bulge or collapse.

If the figures of 14 and 37 horse-power per square foot of grate surface, given above, be accepted as correct for tubulous boilers, and compared with the figures contained in Section 148, we find that the weight per horse-power of the Belleville, D'Allest and Niclausse boilers is two-thirds that of a cylindrical boiler giving 18 horse-power per square foot of grate surface. For the Du Temple or Normand boilers this same ratio falls to one-fourth. It is apparent that for these latter the practical difficulties of stoking in large ships will hardly permit of an output much greater than 18 horse-power per square foot of grate; the ratio of the weights will remain between one-half and two-fifths; and the fact of working the boiler below its maximum capacity must add to the security.

150. *Rapidity in Getting up Steam.*—Pressure can be got up in tubulous boilers within one hour, while cylindrical boilers usually require four hours. This is an advantage in the navy; but its importance should not be over-estimated, on account of the long operation of warming up the engines, to which not less than ten or twelve hours is given on merchant steamers in order to prevent any mishaps. Ease of shipment and rapidity in raising steam are very valuable qualities of tubulous boilers.

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§ 3. VARIOUS CONSIDERATIONS.

151. *Horizontal Space Occupied.*—The horizontal space required by a boiler may be expressed by the ratio of the surface formed by the vertical projection of its horizontal dimensions to the grate area. The division of tubulous boilers into two groups, in respect to forced draught, is also applicable as regards horizontal space occupied.

The Belleville, D'Allest, and Niclausse boilers take up little horizontal space. The coefficient of floor space for the Niclausse boiler, which is the lowest of all, is 1·5; it is 1·7 to 1·8 for the D'Allest boiler, and between 1·6 and 1·7 for the Belleville boiler.

The Du Temple and, above all, the Normand boilers occupy somewhat more space. The coefficient averages 2·5 for the Du Temple and Guyot boilers, and reaches 3 for the Normand boiler.

Going back to cylindrical boilers, and leaving on one side those types whose furnaces are at one end and tubes are at the other, which naturally occupy a large amount of space, it is found that the mean coefficient of horizontal space averages 1·75 for double-ended boilers and 2 for single-ended boilers. The tubulous boilers in the first group are, therefore, superior to those of the second group, but inferior to return-tube cylindrical boilers with the same grate area.

If, for large steamships, the powers per square foot of grate given above for each type be accepted, we find that the tubulous boilers of the first group occupy about the same horizontal space as cylindrical boilers, and those of the second group a space a good deal larger.

Altogether, as regards space occupied on board ship, tubulous boilers are rather at a disadvantage when compared with those of the old type.

152. *Price of Tubulous Boilers.—Their Durability.*—The classification followed in the preceding section holds good from the point of view of cost, as well as working conditions

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but particulars in any way reliable can only be obtained for the boilers in the first group, as these alone, up to the present, have been applied to any extent in large ships. The price per square foot of grate of the Belleville boilers, bought by the French Navy during the last few years, has varied between £27·12 and £35·62; on an average, £31·96. The Niclausse boilers of the *Friant* have also cost £31·96. For the D'Allest boilers the price is a little higher; it has ranged from £27·12 to £38·64; on an average, £33·45. The difference is insignificant, and would bear no influence upon the choice made between these three types.

Comparing the average price of cylindrical boilers with the foregoing, we find it to be £32·7 for single or double-ended return-tube boilers, £48·31 for direct tube or Admiralty boilers, and £52·76 for boilers of the locomotive type. The comparison on this basis is favourable to tubulous boilers. In reckoning the performance per square foot of grate, these tubulous boilers are 25 per cent. dearer than the return-tube boilers, but they are 10 per cent. cheaper than the Admiralty boilers, which have in some cases supplanted the return-tube boilers.

There is only one example of tubulous boilers of the second group being bought for ships other than small craft; that is, the Normand boilers of the *Dunois* and of the *Lahire*, costing £64·65 per square foot of grate. This price hardly affords a fair comparison, as there is no analogous case in the other series of boilers, excepting the cylindrical boilers of the *Fleurus*, which cost £65·39. The Guyot boilers of the *Jeanne-d'Arc*, according to the highest estimate, will only cost £44·59; this price is still high, but it falls below that of the Admiralty type boilers, and, moreover, it is unfair to the Normand and Guyot boilers to assume that the same amount of power per square foot of grate surface could be obtained from boilers of the Admiralty type as from them. As regards price, the tubulous boiler comes out favourably; this would give the Belleville and Niclausse boilers a general advantage, which should be an argument in favour of their adoption, on land as well as afloat, were it not for the question of durability, in respect to which, up to the present moment, there is an absence of definite particulars.

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The Belleville boilers are the only type of tubulous boilers which the French Navy has yet had in service for any length of time. The ease with which the various elements can be replaced renders it very difficult to determine exactly the real life of the boiler; the replacing of the ash-pans and casings, which in itself is a small matter, is to some extent a guide in this direction. The Belleville boilers of the *Milan*, in 1891, had, in the course of a few months, several tubes pitted through sufficiently to put the boat out of service, although they were in good condition when she started, while on the *Voltigeur*, the Belleville boilers, which have been renewed piecemeal during almost twenty years, have always behaved well, and successfully withstood the test of several long commissions.

From the above it is evident that it is very difficult to settle the question of durability.

In the absence of more precise data, as cylindrical boilers are nowadays fitted with steel tubes similar to those used for tubulous boilers, we may assume that they will not, as a rule, receive on board ship, above all in the navy, more care or attention to maintenance than is likely to be given to tubulous boilers.

Just as unfavourable examples can be quoted for cylindrical boilers as for tubulous, as evidenced in the case of the *Marceau* during her Cronstadt commission, where the same thing happened as on board the *Milan*, referred to above, we may therefore arrive at the conclusion that the use of cylindrical boilers does not offer a guarantee of continuous satisfactory working much superior to that of the Belleville boilers.

Further, exact comparison will never be possible between two durabilities of which one only can be defined. The cylindrical boilers of warships have a life of eight years, or at most ten, including at least one thorough overhauling during that period; they are then condemned and broken up, although still containing a good many sound portions, because there is of necessity a limit to patching. At the end of ten years, a tubulous boiler will not have experienced a thorough overhaul, but will have undergone a good many repairs; some parts may have been already changed twice, and even need replacing a third time, without

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in any way prejudicing those portions of the boiler which have remained intact; there is then no reason why the boiler should be condemned.

The foregoing considerations appear favourable to tubulous boilers in regard to durability; but it would be unwise to generalise. Tubular boilers, in certain conditions of work and maintenance, have a very long life without necessitating any very extensive repairs. The case of the White Star Company has been referred to in Section 94, where the boilers worked for twenty-four years, and that of the *Notre Dame du Salut*, whose boilers had undergone twenty years of service up to the time the boat was chartered by the French Navy. A tubulous boiler would not, in all probability, have reached this advanced age without having often had different parts replaced by new ones. Therefore, in shipping companies, directors, when they can depend on their men, prefer the old types, upon which they can rely with greater confidence. On the other hand, when the conditions are altogether against durability, as on torpedo-boats, where locomotive boilers only last three years, tubulous boilers offer a decided advantage; Mr. Thornycroft states that his boilers usually stand eight years' service without extensive repairs, certainly without a thorough overhauling.

153. *Ease of Repairs.—Difficulty in Stopping Tubes.*— Tubulous boilers composed of elements in juxtaposition and generally detachable, can be made good in case of mishap by simply removing the defective parts and replacing them by duplicates. This work can always be done on board even when skilled workmen are not available.

Tubes can be replaced in some boilers with extraordinary ease; thus, in the Niclausse boiler, the replacing of a tube requires no more than two minutes, once the boiler is emptied; in the Belleville boiler, a complete element can be removed and replaced by another in two hours. In the Du Temple boilers and others of the same class, the operation is complicated on account of the necessity of removing several tubes before arriving at the one whose removal is necessary; but each tube can be withdrawn without trouble from its position;

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it only means the slackening of a screw or a few blows with a hammer on a drift; in the D'Allest boiler alone does the removal of tubes present more difficulty than in the case of cylindrical boilers.

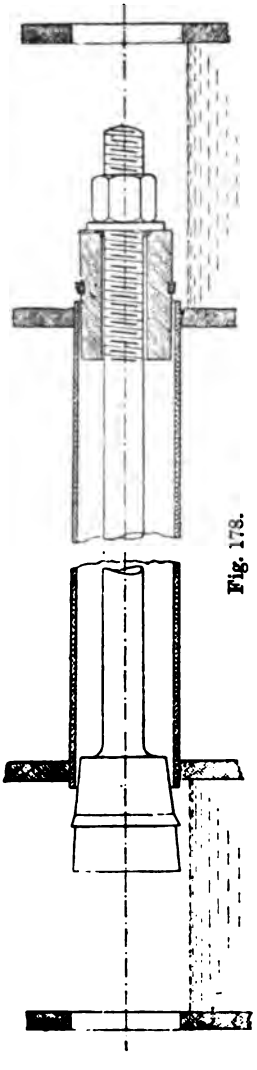

Fig. 178.

Repairs to tubulous boilers, even although they should require a stoppage of a few days instead of merely drawing the fire for a few hours, as is usually the case, are mere child's play when compared with the repairs necessary should overheating occur in the furnaces or combustion chambers of cylindrical boilers.

With regard to facility for carrying out repairs to the boilers while in commission, it must be remarked that the plugging of the tubes while at work in case of their leaking is an impossibility inherent in the principle of tubulous boilers. The emptying the boiler until the water is below the tube that requires plugging, which involves at times the complete emptying of the boiler, is an absolute necessity. As regard plugging the tubes, after the fire is out and the boiler emptied, the various types of tubulous boilers present very different facilities, which depend on their mode of construction. In the Belleville boilers, and in general in all boilers unprovided with collectors, it is impossible to plug the tubes. The damaged pieces always have to be replaced.

In the D'Allest boilers and in all those with straight tubes, the plugging can be done exactly as in cylindrical boilers, by the use of the ordinary arrangement of double plugs.

Fig. 178 represents a plug specially used for the D'Allest

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boilers, which is the design of M. Girard, inspecting engineer in the French Navy.

In the Niclausse boilers, no question of plugging arises, as the operation is precisely the same as the changing of a tube.

In the Du Temple boilers the plugging is very easy, owing to the form of screwed joints used, provided the screw threads inside the collector are in good condition. It is sufficient to remove the nut from the end of the tube and replace it by a blind nut. The blind nuts adopted for this purpose (Fig. 179) are the invention of M. Portay. Owing to the time necessary for the boiler to cool down, the operation takes altogether four

TUBE WITH BLIND NUT.

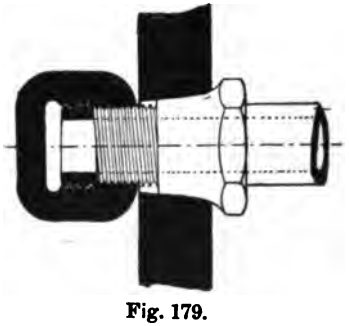

Fig. 179.

CONICAL PLUG USED TO REPLACE TUBE.

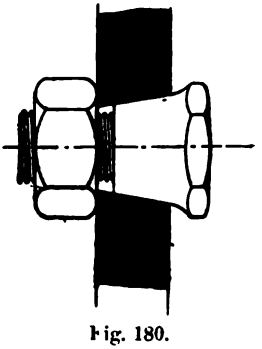

Fig. 180.

hours, counting from the time the fires are drawn until the refilling of the boiler.

If the screw thread is in bad condition and it is necessary to cut the tube so as to insert a plug (Fig. 180) the operation takes at least an hour longer. In the latest boilers with steel joints the necessity of cutting the tubes will be much more frequently met with than was the case with the old pattern brass joints.

In the Normand boilers, and in general in all those wherein the tube joints are made by an expander, the class of plug shown in Fig. 180 could evidently be used; but as a rule a simple conical plug (which sometimes has a slight thread cut on it) is inserted into the end of the tube from the inside

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of the drums. The pressure in the boiler tends to tighten the plug.

The impossibility of plugging a tube while under steam might place a small craft with only one boiler in a very precarious situation during bad weather.

154. *Ability to stand Sudden Changes of Temperature.*—The majority of tubulous boilers, that is to say, the Niclausse boiler amongst those with free circulation, and all the boilers with limited and accelerated circulation, are able to stand without injury the most sudden changes of temperature, as evinced by the fact that the fires can be withdrawn in full swing, and all the doors opened without prejudicially affecting the boiler. M. Niclausse thinks nothing of submitting his workshop boiler to this rude test, to the great edification of his visitors. The similar experience of Mr. Yarrow, described in Section 138, and the method of removing soot employed by M. Normand's stokers, described in Section 48, corroborate the above facts.

It is not fully appreciated, although it ought to be, how sensitive tubular boilers are to sudden changes of temperature even very much less abrupt than those which have just been mentioned. The sudden reduction in the rate of working while under full steam, due to opening the fire- and smoke-box doors, is quite sufficient to stress all the plates of the furnaces, combustion-chambers, and smoke-boxes beyond the limit of elasticity. This gives rise to leaky tube-plates and distortion of the crown plates; and may lead ultimately to leakage along the seams, paving the way for a possible future fracture at the joints. The firing in tubular boilers ought always to be very regular and uniform.

Were it not for the possibility of priming in case of sudden variations of engine-speed, tubulous boilers would enable all and any manœuvres of the engines to be carried out without fear of accident. But as a sudden variation in the speed is liable to produce priming, which may be accompanied by dangerous lowering of the water-level, all abrupt changes in the speed of the engines should be carefully avoided unless absolutely necessary.

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§ 4. DISADVANTAGES OF TUBULOUS BOILERS.

155. *Danger Consequent upon Irregularity of Feed.*—Although tubulous boilers have undeniable advantages when employed for general or more particularly for naval purposes, their advantages are partly counterbalanced by corresponding disadvantages.

It is entirely in their management that difficulties are encountered, and we must now turn to consider them.

On account of the small quantity of water which they contain, tubulous boilers require most careful attention to the feed-supply. A boiler of 55 square feet of grate, working under forced draught, can evaporate 12 tons of water per hour. If the separator up to the working level contains only 1 ton of water, an interruption in the feed-supply would empty it in five minutes; the fall of level in the tubes would then be extremely rapid. The top drum is, as a rule, not in contact with the hot gases, but with forced draught the tubes are exposed to temperatures capable of fusing the steel. The maintenance of the water-level and the management of the feed require therefore very careful attention. In large ships, where several boilers are fed from a common feed-pipe, the adoption of automatic feed-regulators seems to be an absolute necessity.

156. *Necessity of using Pure Feed-Water.*—The tubes of tubulous boilers can only stand the intense heat to which they are exposed when cooled by a continuous circulation of water. Any obstructed tube means a burnt tube; any tube in which a deposit has commenced to form will shortly become an obstructed tube, because the deposits tend to increase due to the retardation of the circulation. Tubulous boilers, therefore, necessitate the use of very pure water, and the use of sea-water must be rigorously avoided, and all the fittings used to purify the feed-water must be kept in good working order.

In conclusion, we may say that the disadvantages of

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tubulous boilers lie mainly in the danger that may result from their breaking down, but this can be minimised by incessant and careful inspection.

Tubulous boilers should on no account be used on board vessels where the loss of feed-water, during its cycle in passing to and from the engines, exceeds 5 per cent., and where this loss is made up from the sea, and more especially if the engineer in charge thinks it beneath his dignity to keep a sharp look out on the stokehold.

There is a fatal prejudice on the subject of boilers which has to be overcome. They are by no means of such simple construction as is often supposed, nor is their management so easy. At present there is no problem in the design and construction of engines which approaches in difficulty those encountered in boiler design; there is no post in the engine-room which necessitates so much constant care, and at times so much ability and presence of mind, as is required for the proper management of the boilers.

5. COMPARISON OF DIFFERENT TUBULOUS BOILERS.

157. *Comparison of Belleville, D'Allest, and Niclausse Boilers.*— The general comparison of all types has been dealt with in the preceding sections; but a few more exact particulars may be added with advantage.

The three types of boilers, Belleville, D'Allest, and Niclausse, are in actual service in three similar cruisers, the *Bugeaud*, the *Chasseloup-Laubat*, and the *Friant*, and detailed information from actual working should be forthcoming. The three engines are, moreover, nearly identical, and were built in the same workshops; the number of expansions, $\left(\frac{D^2}{i\,d^2}\right)$, which are equal to the quotient of the volume of the low-pressure cylinders, divided by the volume of the high-pressure cylinders at the point of cut-off, are the same.

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The principal particulars are :—

	Belleville. *Bugeaud.*	D'Allest. *Chasseloup-Laubat.*	Niclausse. *Friant.*
Grate area . . . . . sq. ft.	758	732	783
Heating surface . . . . . „	21,593	19,451	22,928
Working pressure . lbs. per sq. inch	242	213	213
Total weight of boilers with water as calculated by the builders } tons.	359·2	341·5	329·7
Total finished weight when made, as given by dockyard . . } „	407·4	361·2	363·2
Number of expansions $\frac{D^2}{i\,d^2}$ . . .	7·41	7·41	7·41

The official reception trials gave the following results :—

	Belleville. *Bugeaud.*	D'Allest. *Chasseloup-Laubat.*	Niclausse. *Friant.*
1. *Speed trials.*			
Boiler pressure . . lbs. per sq. inch	224	185	195
Pressure at the engines „ „	162	160	163
Expansions $\frac{D^2}{i\,d^2}$	7·2	7·34	7·63
Horse-Power developed	9,439	9,714	9,438
Coal-consumption { per square foot of grate lbs.	26	23·9	25
Coal-consumption { per horse-power . . .	2·06	1·78	2·03
2. *Coal-consumption trials.*			
Boiler pressure . . lbs. per sq. inch.	194·7	171·5	180
Pressure at the engines „ „	128·7	135·6	141·6
Expansions $\frac{D^2}{i\,d^2}$	12·6	12·59	12·4
Horse-Power developed	3,732	3,536	3,607
Coal-consumption { per square foot of grate lbs.	9·46	10·85	10·25
Coal-consumption { per horse-power . „	1·367	1·48	1·491

The working of all three types of boilers gave entire satisfaction, the Niclausse boiler making a specially favourable

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impression, as it was not so well known, and consequently the excellent results obtained were not expected.

Taking the consumption per hour and per horse-power of the Belleville boiler in the two trials as unity, we obtain the following Table:—

——	Belleville.	D'Allest.	Niclausse.
Speed trials	1	0·858	0·905
Coal-consumption trials	1	1·083	1·089

As regards coal-consumption, the Belleville boiler has the advantage when under easy firing; its good qualities under these conditions have long been recognised.

With hard firing the Belleville is about 20 per cent. less efficient than the D'Allest boiler, and about 10 per cent. less than the Niclausse boiler. These results are what would have been expected; but they have been rendered more striking by the fact that the fires were hardest pushed on the boiler least adapted for it.

On account of the absence of circulation, the steam in the Belleville boilers has to make its way through almost dead water, and ought to give rise to more foaming on the surface and more priming. Further, the transmission of heat by convection is imperfect. The combustion chamber of Belleville boilers is also wanting in height. These are the probable reasons for the inferiority of the Belleville boiler at high rates of working; they are both avoided in the D'Allest, and the first is overcome in the Niclausse boiler. The D'Allest boiler cannot stand hard firing, by reason of its general construction, which restricts the free expansion of the tubes.

In order to arrive at a more definite conclusion, it would be necessary to push the three boilers up to their fullest possible capacity in evaporative trials, in which the feed-water and the dryness of the steam would be measured. The engines could not be worked, as it would not be possible for them to use all the steam produced. The claims of all three makers (and particularly of M. Niclausse), that their boilers are capable of

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working at higher rates of combustion than those realised during the trials of the three cruisers, would thus be substantiated.

Since the reception trials, a boiler on the *Friant* has had a slight mishap through a badly welded tube.

Daily experience confirms the opinion that the Belleville and the Niclausse boilers will stand rough usage and varying temperatures equally well, and both offer facilities for taking apart and repairing, but in this latter respect the Niclausse boiler is superior to all the others. The D'Allest boiler, the construction of which more nearly approaches that of a tubular boiler, has not quite the same facilities in this direction.

158. *Comparison of Du Temple and Normand Boilers with the preceding ones.*—Amongst the types having accelerated circulation the Du Temple and Normand boilers are the only ones of which any lengthened experience has been obtained in the French Navy.

These boilers have never been subjected to a comparative trial with the three types considered in the preceding section; but from a comparison with locomotive boilers, which they have replaced on board French torpedo-boats, it might be concluded that they have, at high rates of combustion, a marked general superiority both as regards good combustion and the utilisation of the heat. It is an established fact that they may be worked at a rate of combustion of 40 lbs. per square foot of grate with greater security than boilers with limited or even free circulation at 30 lbs. Remarkable economical results were obtained from the *Forban*, as noted in Section 40.

The Du Temple and Normand boilers are inferior to the preceding ones, especially to the Niclausse, as regards facilities for cleaning the heating surfaces, inspection, taking apart and for repairs. It is found that they have disadvantages as well as advantages when applied to large ships. On the other hand, their adoption would appear to be compulsory on torpedo-boats, destroyers, scouts and the whole series of small fast craft, and owing to the great advantage of employing a uniform type, this fact is a strong argument in favour of the general adoption of this class of boiler.

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159. *Combination of Tubulous with Cylindrical Boilers.*— In the French Navy, and in the Messageries Maritimes, the problem of the complete substitution of cylindrical boilers by tubulous boilers has been boldly faced. Elsewhere great caution has been shown, and a partial substitution first made, both kinds of boilers being placed in the same stokehold. Such has been the solution adopted in America, for the Ward boilers in the *Monterey*; in Germany, for the boilers of the ironclads *Kaiser-Friedrich III.*, and *Ersatz-Friedrich-der-Grosse*, and on the cruiser *Ersatz-Leipzig*, and a choice is to be made later on between the four types, Belleville, Niclausse, Dürr and Thornycroft now on trial in four cruisers. In Holland this solution has been tried on board the cruisers *Holland, Zieland, Friesland*, which carry two cylindrical boilers and eight Yarrow boilers, and lastly upon a training frigate of the Argentine Republic, which is fitted with Niclausse and cylindrical boilers.

M. Sigaudy has also fitted on board a tug at Bayonne a Normand boiler combined with a cylindrical boiler.

This partial adoption of the new boilers would appear not to have given rise to any inconvenience. The two kinds of boilers, connected to a common steam-pipe, work well together.

It is likely that under this form, and with these restrictions, tubulous boilers may be introduced into the mercantile marine, especially when it is desired to make a trial of a type which has not yet passed through and undergone the test of long use, as the Belleville boiler has already done.

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		Type of Boiler . . .	TE
		Name of Vessel. . .	VER AUPH
General particulars.	1	Working pressure at boilers . . . lbs. p	1
	2	Grate area, total	76·4
	3	Heating surface, total	2,68
	4	Horse-power developed on trial . . .	2,18
	5	Coal burnt per sq. ft. of grate	61·(
	6	Coal burnt per horse-power per hour on trial . .	2·1
I.—Elements varying with the working pressure P and whose weight per square foot of grate ought to be proportional to that pressure.	7	Weight of the body of the boiler without fire-bars or mas	
	8	Stop, safety, blow-off, and reducing valves, separators pipe, and superheaters	6,57
	9	Piping and cocks and valves in stokeholds . .	3,04
	10	Total weights, I.	9,61
	11	Ratio.	87·6
	12	Ratio.	1·9
II.—Elements depending on the rate of working, that is to say, on the quantity of coal burnt per square foot of grate, or on the quantity of water evaporated per square foot of grate. The total of these weights per square foot of grate should be proportional to the combustion K.	13	Feed-pumps	71
	14	Feed-water tanks and reserve tanks . . .	1,4
	15	Feed-water heaters	1,87
	16	Filters, water-purifying apparatus, lime-water tanks	4(
	17	Distillers for "make-up"	24
	18	Water in feed and reserve tanks, and in the abo fittings	4,34
	19	Fans for forced or suction draught . . .	6
	20	Apparatus for heating the air	..
	21	Total weights, II.	9,77
	22	Ratio.	27·4
	23	Ratio.	2·1
III.—Elements independent of both P and K, which ought to be directly proportional to the grate area G.	24	Water in boilers	5,94
	25	Grates, firebricks, and fire-bridges . . .	5,55
	26	Funnels, uptakes and smoke-boxes . . .	2,95
	27	Non-conducting coverings, casings, and lagging of all k	9
	28	Tools and spare gear	59
	29	Stokehold floors and ladders . . .	8(
	30	Total weights, III.	16,8
	31	Ratio.	220·4
Resumé.	32	Total weight . . . . . $P_1 + P_2 +$	56,22 25·1
	33	Total weight per sq. ft. of grate . $A = \frac{P_1 + P_2 +}{G}$	735·9
	34	Horse-power developed on trial per sq. ft. of grate.	28·5
	35	Total weight per horse-power $D = \frac{P_1 + P_2 + P_3}{F} =$	A 25·8

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CHAPTER XV.

WEIGHT AND SPACE OCCUPIED BY TUBULOUS BOILERS.

160. *Table of Weights.*—In calculating the weights of tubulous boilers, the same division and grouping of the constituent parts has been adhered to as for cylindrical boilers, in order to render a comparison of details possible.

As the stress on the materials is very slight in the greater number of the constituent parts, and, above all, in the tubes which constitute the principal portion of a tubulous boiler, considerations of pressure are hardly necessary in determining the thickness; the question of durability is of greater importance. The classification followed, although quite logical for cylindrical boilers, is therefore rather arbitrary for tubulous boilers. In particular, it may be remarked that the ratio of weight, P_1, to the working pressure, Π, is not of much value, but as the pressure, Π, is nearly the same for all the different types of boilers there is no risk that comparisons based upon this ratio would be inexact.

It was only possible to prepare tables as detailed as those given, by borrowing from various sources, and often by trespassing on the kindness of the makers. A great many of the figures, which are taken from the actual finished weights in the shops, are more exact than those supplied by the contractors with the drawings; but it was not possible to obtain finished weights in all cases.

161. *Space Occupied.*—A Table, similar to that compiled for tubular boilers (Chapter X.) is subjoined, and gives the space occupied by the various tubulous boilers referred to in Table I.

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Table II.

Type of Boiler.	Number of Furnaces.	Name of Vessel.	Horizontal Projection in square feet— of the Boiler. c	of the Grates. g	Ratio $\frac{c}{g}$
Belleville	1 furnace	*Alger*	50·80	31·43	1·62
		Latouche-Tréville	70·07	43·38	1·61
		Bugeaud	54·89	34·44	1·59
		Bouvet	59·95	35·52	1·69
		Charlemagne, *Gaulois*	89·98	57·37	1·57
Oriolle	2 furnaces	*Zouave*	54·25	31·43	1·73
	1 furnace	Torpedo-boats, 161 to 163	41·97	24·22	1·73
D'Allest	2 furnaces	*Bombe*	107·10	50·59	2·12
		Jemmapes	138·52	80·73	1·72
		Chasseloup-Laubat	128·83	68·89	1·87
		Cassini	133·45	77·93	1·71
		Carnot	167·92	90·42	1·86
		Du Chayla	63·1	3·44	1·84
Niclausse	1 furnace	*Friant*	266·31	183·39	1·45
		Elan	44·56	21·42	2·08
Du Temple	1 furnace	*Dragon*	78·36	40·69	1·92
		Averne	75·75	38·21	1·98
		Torpedo-boats, 195 to 200	112·48	45·21	2·49
Du Temple-Normand	1 furnace	*Flibustier*	90·42	33·37	2·71
Normand	1 furnace	Torpedo-boats, 148, 149	121·07	35·74	3·39
		Torpedo-boats, 182 to 185	116·23	38·75	3·00
		Forban	128·83	44·13	2·92
Normand-Sigaudy	2 furnaces	*Château-Renault*	239·7	96·4	2·48
		Dunois and *Lahire*	189·85	64·80	2·93
Guyot (Indret)	1 furnace	*Jeanne d'Arc*	101·7	46·16	2·19
Thornycroft	1 furnace	*Véloce*	99·14	37·99	2·61
		Coureur	112·38	38·10	2·95

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PART IV.

CHAPTER XVI.

BOILER MOUNTINGS AND OTHER FITTINGS.

162. *Classification of Boiler Fittings.*—The parts or fittings classed under boiler mountings are very various, and are put to very different uses. Some of them form part of the boiler itself, or at least are fitted to the boiler. Among such may be named the manhole doors, furnace fittings, uptake and funnel. Others again are quite distinct from the boiler, and amongst such may be included the stop-valves, feed-check valves, safety-valves, etc. Others are perfectly independent of the boiler, and may be placed at some distance from it. Amongst these are fittings directly dependent upon the engine, and only indirectly so upon the boiler. For instance, the condenser, though properly a part of the engine, of which it increases the power, is nevertheless an essential fitting for the boiler, as it secures the boiler being fed with fresh water. In this category all the fittings relative to the feed-water may be included. We have already described several fittings which need not be again enumerated here, such as fire-bars, petroleum burners, forced draught fittings, feed-heaters, air-heaters, and so forth.

The study of boiler fittings and their construction might be dealt with at great length, but a short description of them, and a statement of the conditions they are designed to fulfil, must suffice here. Their construction needs great care, and none of the fittings can be ignored with impunity.

163. *Self-Jointing Manholes.*—The manholes and their fittings

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are almost the only accessories that form part of the actual boiler-shell.

Formerly, with rectangular boilers, the manholes might be placed in almost any convenient position; those to gain access to the steam space were usually placed on the crown of the boiler. With the present higher pressures the number and size of the openings are reduced, to obviate, as much as possible, cutting any openings in the circular shell, the manholes in cylindrical boilers being placed on the boiler fronts, and in tubulous boilers upon the two ends of the cylindrical collectors or steam drums. These manholes are strengthened throughout their circumference by a stiffening ring of plate, or, better still, angle-iron, to compensate for weakening the shell plate, and to give the stiffness necessary for drawing up the joint.

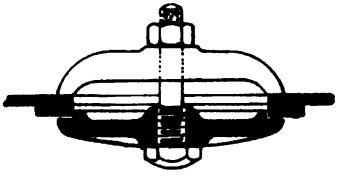

Fig. 181.

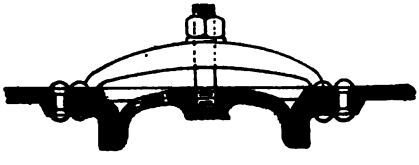

Fig. 182.

The door is always self-closing; that is to say, held up to the joint by the boiler-pressure itself. It is a forging or stamping placed inside the boiler, and held in position by a screwed bolt passing through a bridge or "dog," applied to the outside of the boiler. Fig. 181 shows a type of manhole and door of an early design; Fig. 182 shows the present type, which exhibits a considerable advance on the former, on account of the increased stiffness of the edges and the greater facility for machining the same.

164. *Furnace and Ashpit Doors.*—The furnace doors are pierced with holes for the passage of air, and fitted on the inside with perforated baffle-plates to prevent overheating. The old style of door, turning upon vertical hinges and closing with a latch, has now been superseded by the "Martin" door, hung upon a long horizontal hinge and closing automatically.

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The object of this change is to reduce, as much as possible, the length of time the doors are open when stoking.

The new doors open inwards, and tend to close by their own weight, so that, should an escape of steam take place in the furnace, the rise of pressure only tends to close them more firmly. Two stokers are needed for firing, as the doors require to be held open by hand. This is not a serious disadvantage, because the fires are never charged together and it does not really entail any extra work.

MARTIN FURNACE DOOR.

Section on A B.

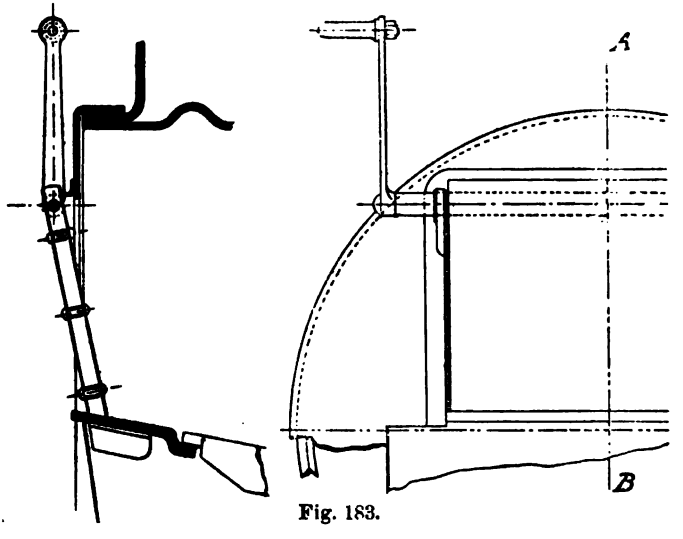

Fig. 183.

The ashpit-doors regulate the supply of air; they are usually constructed with two wings, each one having a small opening, which is closed by a "butterfly" shutter.

It is a simple matter to construct the ashpit-doors in such a manner as to make them close automatically, to act as a safety device in the event of an escape of steam. This arrangement is compulsory on board French torpedo-boats having locomotive boilers, and is now becoming general.

This precautionary measure is not of so much importance as in the case of fire-doors, because the escape of flame from the

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ashpit-doors very rarely occurs, on account of the resistance offered to its passage by the coal and fire-bars.

ARRANGEMENT OF FURNACE DOOR OF TORPEDO-BOAT BOILER.

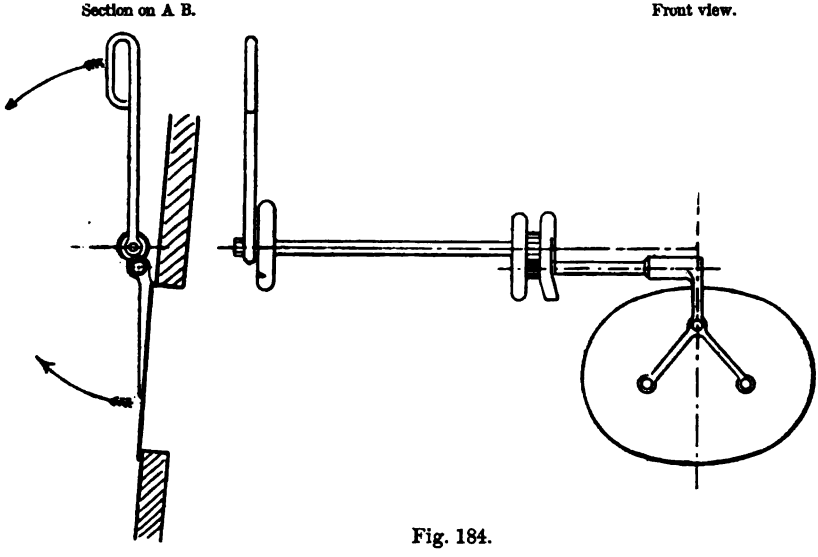

Fig. 184.

165. *Funnel Casings and Funnel Covers.*—With the older types of tubular boilers having very thick shells, to which the smoke-boxes were solidly bolted, the funnels were provided with a seating sufficiently strong to meet all requirements; they rose up through their hatchways, and expanded freely, without more attention being necessary than to take care the stays were sufficiently slack to allow of expansion on lighting up.

ASH-PAN DOOR OF TORPEDO BOAT BOILER.

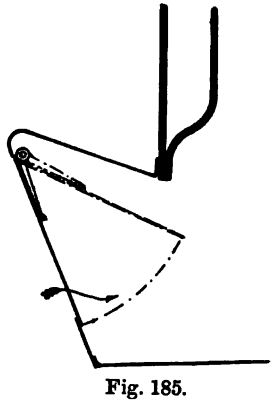

Fig. 185.

The funnel casings are fixed, the one to the hull, the other to the funnel; there must be contact, but no joint, between the hull and funnel portions, and they must always be able to slide freely one upon the other; no difficulty has been experienced

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in this arrangement, either in construction or working. This simple method is the one most frequently adopted, especially on passenger-vessels. With closed stokeholds, the adoption of forced draught introduces a slight complication by necessitating the use of some closing device in the casings.

On torpedo-boats, the top of the casing is simply closed by an angle-iron ring, or flanged plate, on the flange of which the funnel slides when expanding. But, on ships where the casings have to serve for the escape of the heated air, it is necessary to fit shutters (Fig. 187).

TORPEDO-BOAT FUNNEL.

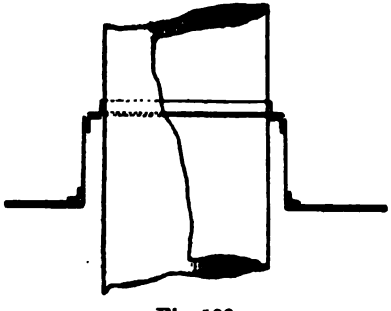

Fig. 186.

SFAX.

FUNNEL CASING WITH SHUTTERS.

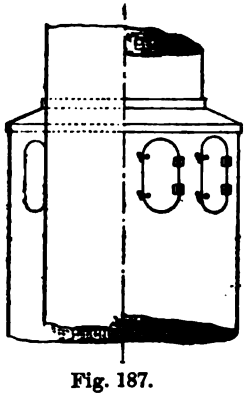

Fig. 187.

The introduction of tubulous boilers, having casings of thin plates not strong enough to stand heavy strains, has necessitated some modification of the older type, and thrown upon the hull itself the duty of supporting the greater part of the weight of the funnel, and also the tension of the stays. In modern practice the boilers only support the lower portion of the funnel, chiefly the portion where the greatest expansions take place. The upper part of the funnel, with the whole of the casing, forms a framework riveted to the surrounding edges of the hatchways. The two parts of the funnel thus divided slide over one another, and are united by a very simple expansion joint packed with asbestos or silicate cotton. The figure 188 shows an arrangement of this description adopted on the *Friant*.

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The whole of the upper part of the funnel thus becomes, strictly speaking, an accessory of the hull and not of the boiler.

FRIANT.

FUNNEL STUFFING-BOX.

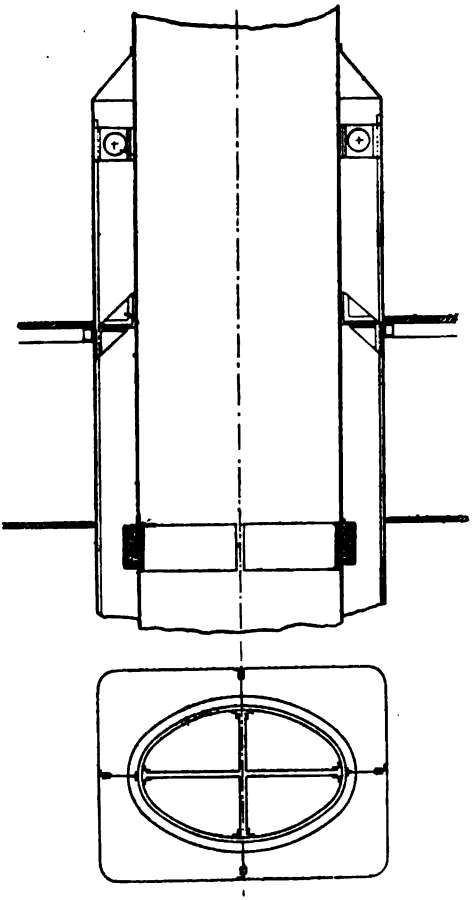

Fig. 188.

The top of the funnel should be closed by a cover during periods of inaction or when laid up, to keep out rain and moisture; the soot, when dry, constitutes a good preservative coating, but when damp becomes, on the contrary, an active

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destructive agent to the plates. On the older ships it was thought sufficient to provide canvas coverings, which were placed in position by being suspended from a stay. In the

CHARLES MARTEL.

FUNNEL COVER.

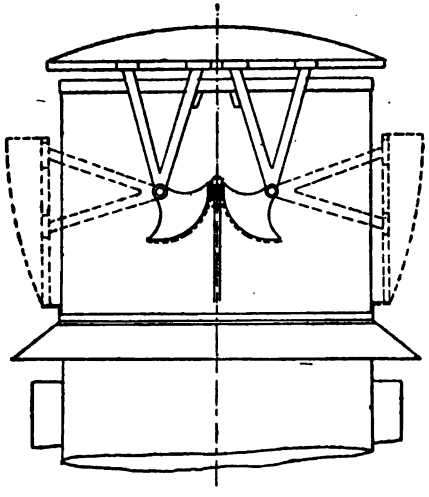

Fig. 189.

French Navy funnel covers of thin plate are now provided, turning on a hinge, and worked from the deck by means of chains or rods, as shown in Fig. 189. A flexible roller shutter of thin plate has also been tried, but its excessive weight has caused it to be abandoned.

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CHAPTER XVII.

BOILER STEAM FITTINGS.

166. *Pressure-gauges and Sentinel-valves.*—Bourdon pressure-gauges are those most commonly used; they are most simple in their manner of working, and the readings are uniformly reliable; they are easily fixed, but care should be taken to place them in a well-lighted and convenient position.

It is very essential that an automatic signal should be conveyed to the stokehold when the pressure approaches that at which the safety-valves are adjusted to blow off. This duty is fulfilled by a small safety-valve, termed a "sentinel" valve, which is fixed on the boiler front, having its blow-off pipe carried into the stokehold. In the French Navy this valve has a diameter of only $\frac{3}{16}$ of an inch. The valve seat is flat, and the load is adjusted by means of a spring, in the same manner as the main safety-valve. The valves are also closed up in such a manner that the load on them cannot be tampered with. Under these conditions the guarantee of their reliable action is precisely the same as for the main valve. The sole object of these sentinel-valves is to prevent the lifting of the main safety-valve through unforeseen excess of pressure. In the American Navy these sentinel-valves, instead of being loaded by a spring, are directly loaded with weights placed upon the valve spindle. Many engineers have more confidence in the direct action of weights than in springs. On the other hand, the weights, although having a decided advantage on shore, have at sea the great disadvantage of allowing the valves to blow off at varying pressures when the ship is in a rough sea, due to the inertia of the weight; this has led to direct weights for safety-valves and sentinel-valves being abandoned in the French Navy.

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167. *Safety-valves.—Calculation of their Area.*—Although for regulating the water level it is generally considered sufficient to rely upon the man in charge adjusting the feed by hand, for the pressure, on the contrary, it is absolutely necessary to have an automatic regulator, and this is fulfilled by the safety-valve. The safety-valves of marine boilers were, years

BOUVET

DOUBLE SAFETY-VALVE.

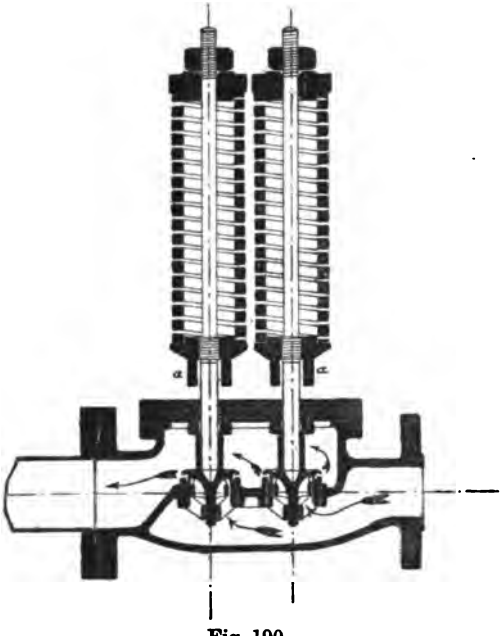

Fig. 190.

a. Easing levers.

ago, loaded by means of a counter weight acting upon a lever; several valves of this type are still in use. The variations in the weight tending to keep the valves shut, which we have alluded to above, led to the counter weight being replaced by two steel spiral springs. The heads of the two springs pull on a cross-bar, pressing directly upon the valve spindles; stop rings are fitted in such a manner as to prevent the springs being strained beyond the tension corresponding to the boiler pressure.

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Arrangements are always made to allow the safety-valves being eased off their seats by hand, at all pressures. With the older types the counter weight was eased by means of a pedal attachment worked by a screwed rod. With spring safety-valves the easing gear is arranged so that the cross-bar or yoke is lifted by means of a lever and a screwed rod. The hand-easing gear must always work freely and quickly. Upon all ordinary occasions it must also be capable of easing the valves slowly and gradually, because any abrupt fall of pressure is very liable to start priming; on the other hand, should an accident occur, it may be necessary to be able to lift the valve with all possible speed.

The waste-pipe from the safety-valves is now frequently led into the condenser and not into the open air. This causes a slight complication in the pipe arrangement, but is more than compensated for by important advantages: the loss of fresh water is obviated, and also the deafening noise of the steam escaping from the waste-pipe above the deck; besides, in case of leaks, the outlet into the condenser prevents the steam from getting into the stokehold. The area of escape of the valves must be sufficient to allow free passage, under full working pressure, to all the steam the boiler can produce when the engines are stopped. The Board of Trade rules require an evaporation trial lasting twenty minutes, with the fires pushed and as little feed as possible. In France, however, it is considered sufficient to require a minimum area, determined by empirical formulæ, of which many exist. The rule usually adopted for some time past in France was established by supposing the rapidity of escape to be determined by the formula

$$V = \sqrt{2gH}$$

in which H is the height of the gaseous column $\frac{p_0}{d}$.

If P_0 is the working pressure and d the weight of one cubic mètre of steam, calculated according to the laws of Mariotte and Gay-Lussac for gases, then

$$d = \delta \times \frac{1{\cdot}293}{1000} \times (p_0 + 1)\frac{1}{1 + at}$$

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The volume of steam flowing per second is ΩV, and its weight is

$$\pi = \Omega V d = \Omega d \sqrt{2g\frac{p_0}{d}} = \Omega \sqrt{2g p_0 d}$$

which gives, collecting all the constants in one single one M,

$$\pi = M\,\Omega \sqrt{\frac{p_0 (p_0 + 1)}{1 + at}}$$

Admitting, on the other hand, that the weight π of steam produced per second is proportional to the heating surface S, then M_1 being a new constant,

$$M_1 S = M\,\Omega \sqrt{\frac{p_0 (p_0 + 1)}{1 + at}}$$

$$\Omega = \tfrac{1}{4}\pi D^2 = \frac{M_1}{M} S \sqrt{\frac{1 + at}{p_0 (p_0 + 1)}}$$

from which M_2, being a factor containing only constants, is deduced—

$$D = M_2 \sqrt{S} \sqrt[4]{\frac{1 + at}{p_0 (p_0 + 1)}}$$

where approximately, in modifying the constant to bring in the factor $1 + at$ assumed to be constant, and in replacing $p_0 + 1$ by p_0—

$$D = M_3 \sqrt{\frac{S}{p_0}}$$

The following empirical formula has been arrived at by experience, the pressure being stated in atmospheres—

$$D = 1{\cdot}3 \sqrt{\frac{S}{p_0 + 0{\cdot}588}}$$

Calling P_0 the absolute pressure $p_0 + 1$, the formula may be written—

$$D = 1{\cdot}3 \sqrt{\frac{S}{P_0 - 0{\cdot}412}}$$

As a precaution, the diameter D is doubled, thereby quad-

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rupling the area, which gives the formula at present in general use in France—

$$(1) \qquad D = 2{\cdot}6\sqrt{\frac{S}{P_0 - 0{\cdot}412}}$$

thus ensuring a rapid fall in pressure when the valves are opened.

The formula (1) was employed in the French Navy for a long time, and is still sometimes used; but, independently of the small amount of value to be attached to the theoretical principles upon which it is based, it gives the value of D in terms of the heating surface, which, in marine boilers, represents very inadequately the power of steam production.

At the present time another formula is in use at Indret, introduced by M. Brosser, where if π is the quantity of steam in kilogrammes per second escaping from an orifice of area Ω, we have—

$$\pi = \Omega(25{\cdot}5 + 144{\cdot}5\,P_0),$$

or,

$$\pi = \Omega(170 + 144{\cdot}5\,p_0),$$

P_0 and p_0 being taken in atmospheres. The production of steam per second of the boiler is always approximately,

$$\pi = \frac{8\,G\,C}{3600}$$

G being the grate area in square mètres and C the coal consumption per hour per square mètre of grate. M. Brosser thus arrives at an evaporation of eight kilogrammes of water per kilogramme of coal, a fairly accurate figure, though low for modern practice.

The equation

$$\Omega(170 + 144{\cdot}5\,p_0) = \frac{8\,G\,C}{3600}$$

gives for the diameter expressed in mètres the value

$$D = \sqrt{\frac{32}{3600\,\pi}}\sqrt{\frac{G\,C}{170 + 144{\cdot}5\,p_0}}$$

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M. Brosser assumes a constant value for C equal to 80 kilogrammes per square mètre per hour, on the assumption that the forced draught can be stopped instantly when it becomes necessary to get rid of the steam. In giving C this value, and in substituting the effective pressure p_0 in atmospheres for the pressure p_1 in kilos per square centimètre, the formula becomes—

$$(2) \qquad D = 0{\cdot}242 \sqrt{\frac{G}{175{\cdot}61 + 144{\cdot}5\, p_1}}$$

Trials made at Indret have proved that the formula (2) gives areas capable of allowing the passage of twice the amount of steam produced by quick fires and natural draught. By means of this formula the diameters of a series of valves have been determined which suffice for all sizes of boilers. It is necessary, in order to get convenient sizes, to reduce the diameter D and make the valves double, that is to say, to arrange two valves side by side having one steam inlet and escape-pipe common to both.

168. *Safety-valves with High Lift.*—It is assumed in the preceding formulæ that the lift h of the valve gives an area of escape, $\bar{\omega}\, D\, h$, at least equal to the area $\frac{1}{4}\bar{\omega}\, D^2$, that is to say,

$$h \geqslant \tfrac{1}{4} D$$

When the lift of the valve has been determined in such a manner as to fulfil this condition, it is a somewhat difficult problem to obtain the maximum lift and at the same time ensure that the pressure does not rise sensibly above p_0, since the springs being short, their tension increases very considerably with the lift of the valve. The problem is solved by utilising the reaction of a jet of steam projected at great velocity against an obstacle which deflects it. Fig. 191 shows the form of valves adopted at Indret. In addition to the dynamic reaction exercised against the valve and its flange, as soon as the steam commences to escape a certain static effort is exercised on the flange. The extra tension on the spring is thus counterbalanced, and the valve gets its full lift.

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The Figs. 192 and 193 represent other forms of valves where, to arrive at the same result, the dynamic action alone is made use of.

The actual valve face is not acted upon by the pressure when the valve is shut but is subjected to it when the valve lifts; there are therefore two pressures, the pressure of opening and the pressure of closing. Formerly, with the conical seats, the pressure was calculated on the larger diameter, the working pressure being the pressure at which the valves would close; the ratio of the two surfaces was equal to 1·17, and therefore boilers calculated for a working pressure of 32 lbs. should not have blown off until a pressure of 37 lbs. was reached; as a matter of fact the valves lifted at about 35 lbs., commenced beating, and were barely closed when the pressure had fallen to

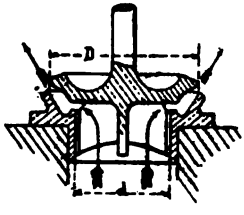

Fig. 191.

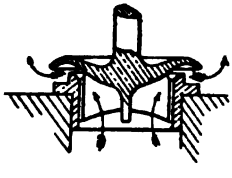

Fig. 192.

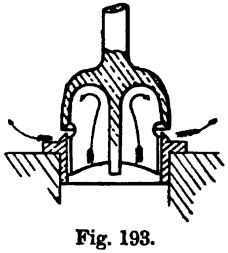

Fig. 193.

32 lbs. At present the weight on the springs is calculated from the small diameters and made equal to 1·66 Sp_1; that is to say, greater by 5 per cent. than the nominal working pressure. The valve seat is flat; the width of the seating is reduced to about $\frac{3}{64}$ of an inch, or $\frac{3}{32}$ of an inch at most, so as to make the boring or grinding in of the seats and valves an easy matter; it also reduces the difference between the opening and closing pressures, and consequently reduces the amount of beating on the seats. The grinding up of the seats and valves must always be done with great care. Formerly, with the large conical valves, it was necessary to turn and bore them while hot, on account of the deformation of the valve chests, due to expansion, and absolute tightness of the valve was very rarely realised in practice. Safety-valves must always be under careful supervision; they should be eased from time to time in order to

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get rid of dirt and scale which otherwise might cause the working pressure to be exceeded by several pounds. The valves, as well as the seatings, are of gun-metal in order to avoid trouble through oxidation. The valve chest itself is either of cast iron, or, preferably in modern practice, of cast steel.

169. *Stop-valves.—Sluice or Regulating Valves.*—The stop valves are fitted upon the boiler itself, and are designed to control the passage of the steam from the boiler to the whole of the steam piping. Similar valves are fitted upon the communication pipe leading from one boiler to another. Stop-valves must be above all simple in construction and certain and quick in action. The valve is loose upon its spindle, and the spindle, screwed

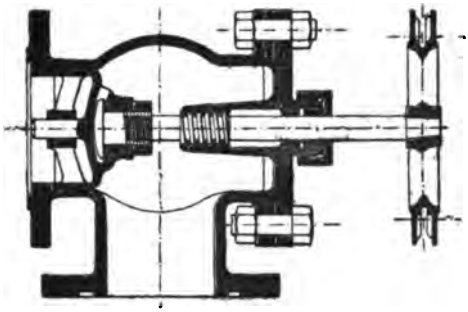

Fig. 194.

through a guide placed outside or away from the steam, receives a rotary motion to open or close it. The valve is worked by a chain wheel with endless chain, which is carried down to a convenient position in the stokehold. The stop-valve should be constructed to shut automatically in the event of any considerable fall in pressure in the boiler upon which it is fitted. This arrangement is stipulated for in the Royal Navy.

The stop-valve upon the boiler and the throttle-valve on the engines were for a long time the sole means of shutting off steam from the steam-pipes. The stop-valves, which are considerably tighter than the throttle valves, are capable of preventing the passage of sufficient steam to move the engines, but leak enough to be troublesome when disconnecting the pipes or opening up the engines under steam.

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During the last ten years it has been usual to fit a valve, similar to a sluice-valve, in addition to the stop-valve, which is capable of being wedged tightly up into its conical seating, and is perfectly steam tight.

There are many different types of these valves, but they all

CIRON VALVE.

Fig. 195.

MULLER VALVE.

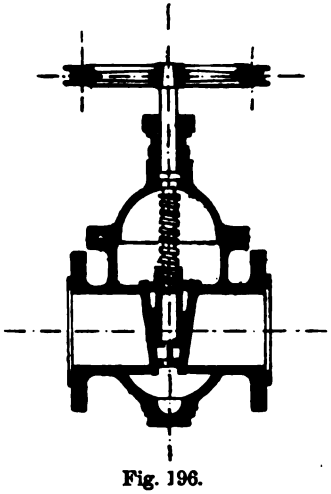

Fig. 196.

work upon the same principle; the spindle causes, in the first place, the bodily movement of the plug, then its tightening in the seat when being shut; upon opening, the first motion is the loosening of the wedge-like plug, then the movement of the whole plug. This arrangement requires great care both in the construction and fitting.

The Ciron valves (Fig. 195) are subject to an additional wedging action on the first movement of the spindle which renders the opening somewhat difficult; the Muller valve (Fig. 196) is a more reliable type. On account of their complication, this description of valve is not used on pipes of a lesser diameter than about 2½ inches.

Owing to the large flat faces of the conical plug and its seating, the fatigue of the material due to the steam pressure, and the strains set up by the longitudinal expansion of the steam pipes, are very great.

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The earlier types, made with cast-iron chests similar to stop-valves, have given rise to serious accidents, attended in some instances with fatal results. Modern practice constructs these chests in gun-metal or cast steel, steel being used when the temperature of the steam approaches 360° Fahr. A spherical form of chest has also found favour, and great care is exercised to allow of free expansion of the piping in the expansion joints near these valves, with the result that there is a comparative immunity from accidents.

Notwithstanding these improvements, the multiplication of safety fittings is not without its inconveniences. Safety appliances, owing to the accidents to which they are themselves liable, constitute a certain element of danger. There is now a strong tendency towards simplification, and attempts have been made to reduce to two the three separate systems of piping recently fitted on some boilers, of which one set was for the main engines, the second for their auxiliary apparatus, and the third for the various separate engines, such as dynamos, winches, pumps, etc. An automatic valve which shuts off the steam in the event of any serious leak, would be a safety fitting of great value.

170. *Reducing Valves.*—Under this heading are classed a large number of apparatus in general use, apart from the engine itself, for supplying, at a lower and determined constant pressure, the gas or steam produced by a reservoir at a higher pressure.

The principle of the apparatus is as follows:—

The regulating valve is pressed from below by the engine steam, above by a resisting spring, the tension of which is set according to the working pressure desired; it is in no way subjected to the boiler pressure. The ports are sometimes arranged round a sleeve and their opening is regulated by the tension of the spring. Consequently, as soon as the pressure falls on the engine side, the admission is increased and brings the pressure up to its normal amount.

The reducing valve works, therefore, like a kind of automatic governor, but with the advantage of rendering the speed more constant than with the ordinary governor. Taking, therefore,

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an engine working at 170 lbs. per square inch, and receiving, through a reducing valve, steam from a boiler working at 240 lbs. per square inch, and supposing that the production of steam accidentally falls, the speed of the engine will not be influenced as long as the pressure in the boiler does not fall below 170 lbs., that is to say, so long as the engine has not consumed $\frac{240-170}{240} = \frac{7}{24}$ of the steam in reserve; but irregularities in working are, generally speaking, of short duration, and do not give rise to variations in the steam production as great as the above.

Belleville Reducing Valve.

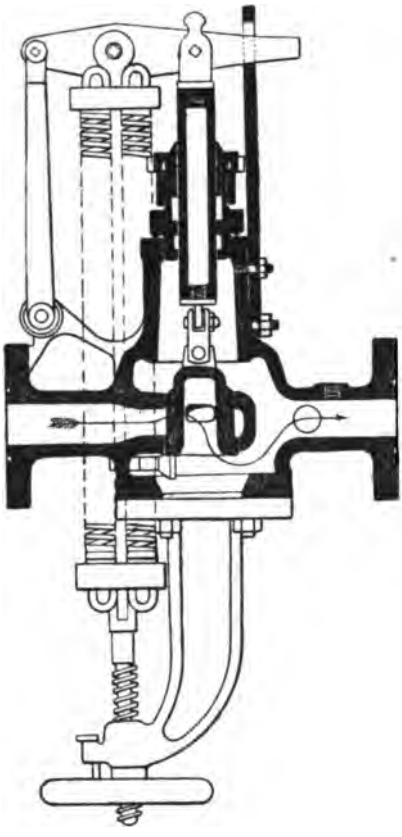

Fig. 197.

The reducing-valve is an essential fitting to the Belleville boiler, the working pressure of which is generally about 240 lbs. per square inch, whilst the pressure at the engines, dependent upon the speed required, does not usually much exceed 170 lbs. They have now been in use for over twenty years on these boilers, as the small volume of the steam-collecting drum renders the engine particularly sensible to the least variation in the production of steam. Its effect is to totally neutralise the influence of variations of pressure up to 70 lbs. per square inch, which corresponds in boilers without reducing valves, having a steam chest ten times larger, to variations of 7 lbs. only for the same irregularity of firing.

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The reducing-valve, in preventing variation in the speed of the engine when the pressure rises, prevents in an effectual manner the tendency to prime, to which the Belleville boiler was for a long time especially subject. On the Belleville boilers they are placed on the main steam-pipe, after the steam separator.

Reducing-valves, in common with all fittings that give rise to wire-drawing, produce slight superheating, equal, for saturated steam, to half the fall in temperature, dependent on the fall in pressure.

The reducing-valve is not suitable for effecting the instant changes in speed which are frequently required in the engines on a warship. Though not a necessity with other types of tubulous boilers, fitted with larger steam receivers than those on the Belleville boiler, their use is nevertheless becoming more general.

171. *Steam Piping.—Expansion Joints.—Steam Traps.*— Copper steam-pipes, which replaced the early cast-iron piping, satisfied for a long time the requirements and necessities of marine work. The material was easily worked, of lasting quality, and of sufficient strength to withstand the pressures and temperatures used. The failure of copper pipes of large diameter was, however, always a danger to be feared. They ruptured, not at the brazing itself, but close to it, due to local heating similarly to the fractures that occurred in welded furnaces. The adoption of high pressures has rendered the strength of copper pipes insufficient, not so much on account of the increased stress on the metal, as from the deterioration which takes place at or about a temperature of 400° Fahr.

Remedies for this failing have been sought in strengthening copper pipes either with iron rings placed close together on the pipe, or by completely binding it with steel or iron wire so arranged that the rupture at one place does not loosen the whole coil.

At present large main steam-pipes are usually made of steel, with riveted joints. The flanges, T-pieces, bends, etc., are usually made of cast steel.

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The tensile strength is thus assured but the upkeep requires great attention, and their life will probably not be greater than that of the steam-collectors of boilers of similar diameter and thickness.

The principal cause of fatigue which has always to be feared in steam-pipes, no matter of what material they may be constructed, proceeds from expansion. This is sure to lead to ultimate rupture of the pipe unless proper means are provided to take it up.

When using copper, much was expected from the flexibility of the metal itself. On the low-pressure exhaust to the condenser the pipes were sometimes shaped as shown in Fig. 198. On steam-pipes right-angled bends are more often resorted to

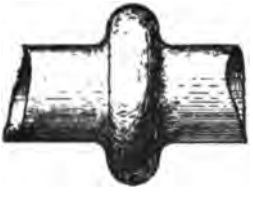

Fig. 198.

EXPANSION JOINT.

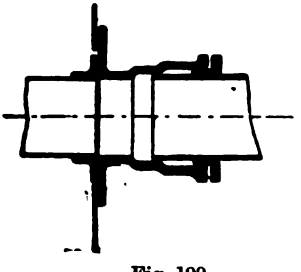

Fig. 199.

to give the desired flexibility, but the bends are still apt to give way at the collar, where the flange is rigidly fixed. On long lengths of straight piping, expansion joints, as shown in Fig. 199, are used, but they sometimes get jammed and fail to act, and have been the cause of fracture in pipes, the high temperature of which has rendered the metal forming them brittle. With the steel piping now in use, expansion joints are the only means of taking up the expansion in the piping. Provided the piping does not get out of line and is well guided, this arrangement works very well. Steam-piping must therefore be composed of straight lengths which are carefully guided and united to one another by expansion joints.

It is essential to secure, and make provision for, the drainage of any water that may find its way into the piping, more

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especially where a change of direction in the piping may form a pocket.

In spite of all precautions taken to ensure dry or superheated steam for the engines, condensation is sure to take place in the piping, sometimes in considerable quantities, more particularly when the engines are standing, or during warming up before getting under way. If steam is suddenly admitted into the piping it meets there a mass of cold water, which causes it to condense, and to which it transfers its heat and energy. The mass of water thus put in motion, assisted by the incoming steam, may give rise to local shocks, which severely strain the piping; it may even subject the metal to stresses higher than those to which it was subjected during the hydraulic tests. This explains the rupturing of the pipes on starting up the engines, which has sometimes given rise to grave consequences. The bending over of the sides of the fracture is evidence of the intensity of the shock which caused it.

The engineer in charge must always be most careful to thoroughly drain his piping before starting his engines.

172. *Separators and Superheaters.*—The fittings used to transform into dry steam the more or less wet steam that is given off by the boiler may be divided into two classes:—

(*a*) Those that dry the steam mechanically;
(*b*) Those that dry the steam by adding heat thereto.

The mechanical steam-dryers are all based upon the same principle, viz., of causing the steam to make a sudden change in its direction, thereby depositing the water, owing to its greater momentum, on the walls of the apparatus.

The separators used by the Belleville boilers, and forming an integral part of the same, extract a large amount of water and prevent it passing into the piping. They are described in Section 100, and shown in Figs. 116 and 117. Separators are usually placed near the engines to stop any water coming over from the boilers, or that may have been condensed in the piping itself, from finding its way into the engines. They are almost universally employed with tubulous boilers, and often with cylin-

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drical boilers. Separators are generally composed of a vertical cylindrical reservoir with a baffle down the centre, which forces the steam to take the course indicated in Fig. 200. The water thrown on to the sides of the vessel collects at the bottom and is drawn off by a trap or drain-cock, a gauge-glass being fitted to indicate the height of the water in the separator.

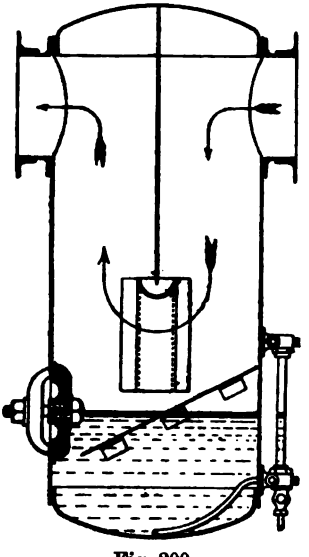

Fig. 200.

As any neglect in draining this vessel might lead to serious consequences, it is advisable to fit a reliable automatic trap. The Belleville boilers in particular adopt this automatic arrangement, as shown in Fig. 201, where the float, instead of acting direct on the drain-cock itself, works a small steam piston, which in its turn works the draining gear.

Frequently the fittings described in Section 182 as oil separators, and shown in Figs. 223 and 224, are used as steam-dryers, being placed close to the engines on the main steam-pipe.

Those separators which work on the principle of adding heat to the steam are known as steam-dryers or superheaters according to the quantity of heat which it is intended to add; that is to say, according as it is desired to obtain dry saturated steam, or steam heated some degrees above the point of saturation. There is, after all, not much difference between the two, except for the amount of surface, and they usually form a kind of supplementary boiler placed at the base of the funnel.

The boilers designed by M. Dupuy de Lôme were fitted with superheaters on this principle (Fig. 202), but they were of little use.

Lafond superheaters were tried at about the same time and were composed of large bent tubes fitted into the base of the funnel.

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AUTOMATIC DRAIN ON STEAM SEPARATOR.

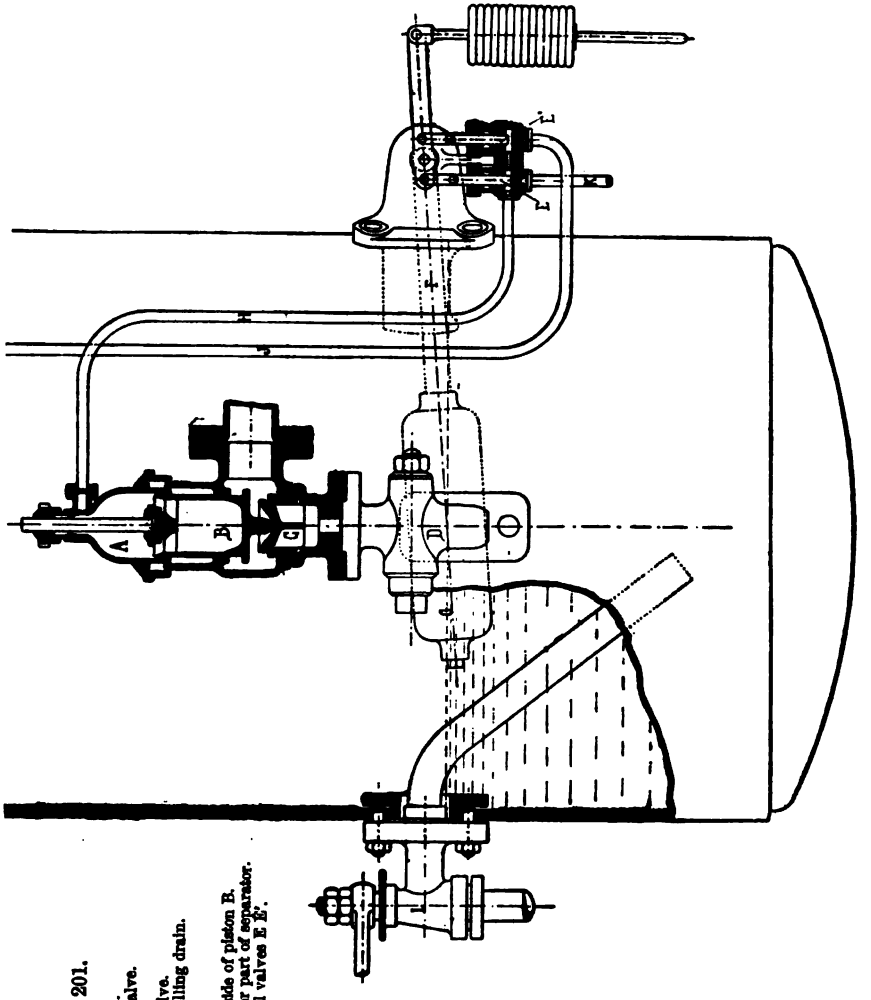

Fig. 201.

A. Automatic drain.
B. Piston of drain-valve.
C. Valve.
D. Inlet to drain-valve.
E E'. Valves controlling drain.
F. Valve lever.
G. Float.
H. Steam to upper side of piston B.
J. Steam from upper part of separator.
K. Drain from small valves E E'.
L. Hand drain.

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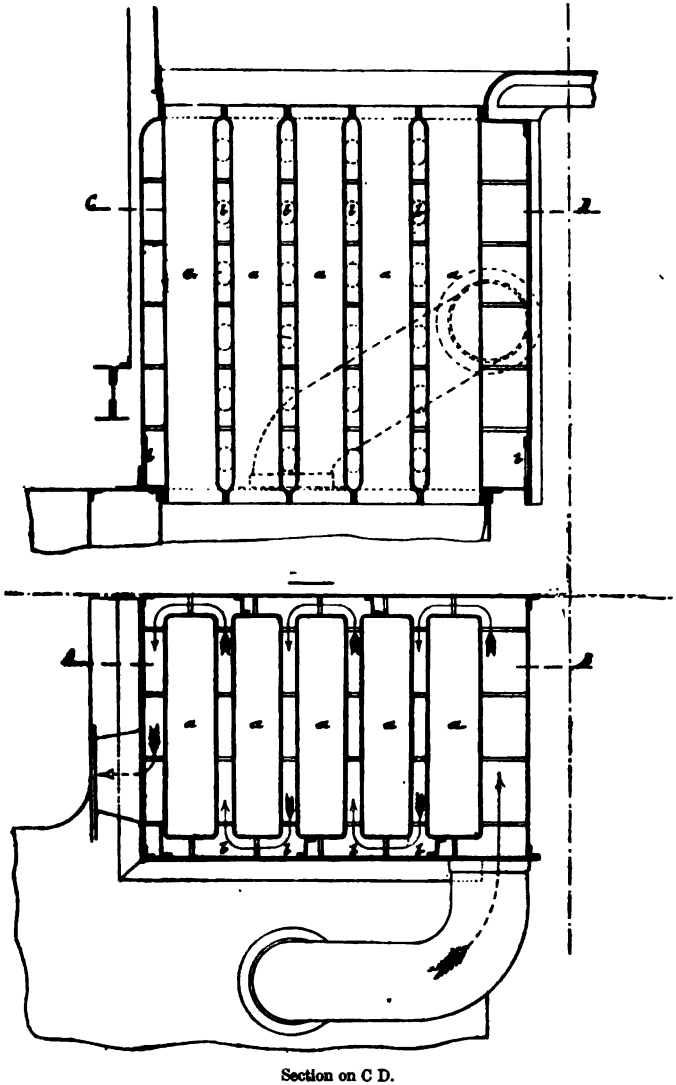
PROVENCE.

SUPERHEATER.

Section on A B.



Section on C D.

Fig. 202.

A. Passages for the hot gases. B. Inspection or manhole doors.

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JÉRÔME NAPOLÉON.
LAFOND SUPERHEATER.

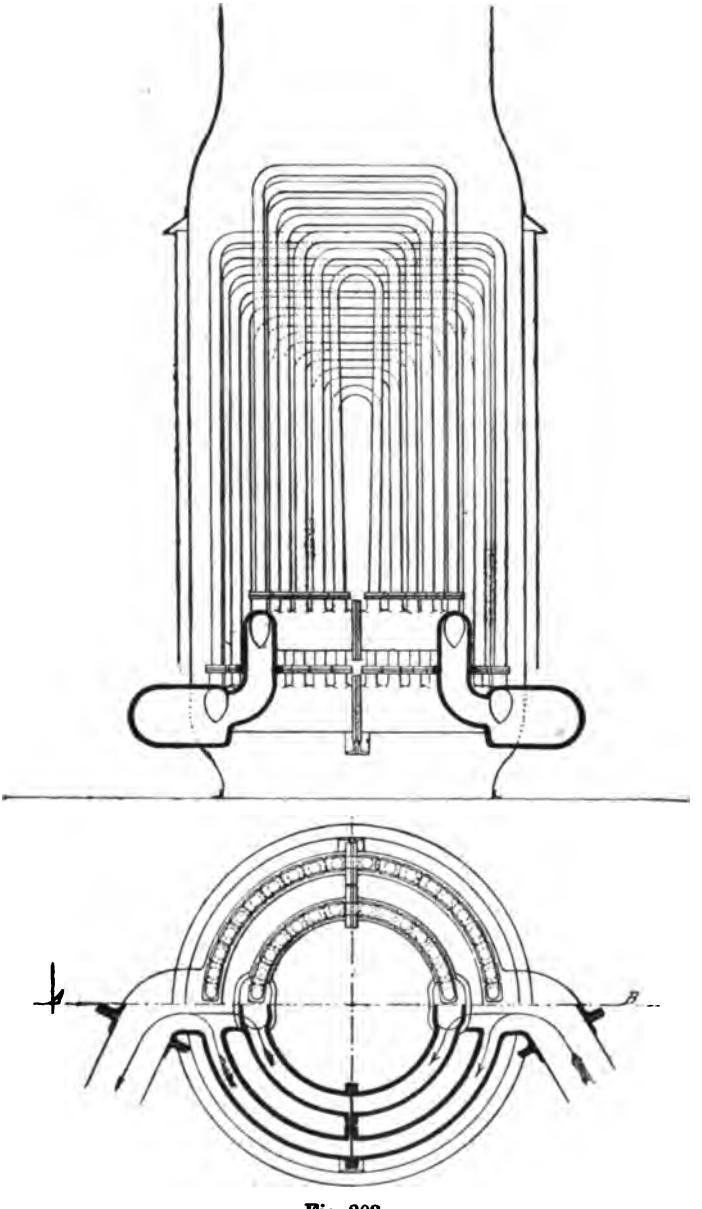

Fig. 203.

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The apparatus was heavy, occupied a lot of space, and was of very little good, being taken out after it had been in service for a very short time.

Steam being a bad conductor, necessitated the use of large surfaces, which entailed heavy weights and the occupation of a large amount of space, and this has led to the complete abandonment of superheaters on board ship, in spite of the theoretical advantages of superheated steam.

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CHAPTER XVIII.

FEED ACCESSORIES.

173. *Water-gauges.— Gauge-cocks.*— The question of the quantity of water in all marine boilers is one of special interest, not only in tubulous boilers, but in those of cylindrical form, as the importance of keeping down weight on board ship has a tendency to reduce to a minimum the amount of water allowed, and thereby lowers the water level in the boiler. In cylindrical boilers the normal water level is usually about 8 ins. above the top of the combustion-chamber. The majority of serious accidents of which the cause could be determined, have been due to the lowering of the water level. For instance, on the torpedo-boat No. 122, where the splitting of the crown of the furnace caused the death of a stoker, it was proved that the water-gauges were not registering correctly. On the *Wattignies*, in the same way, it was proved that when a Fox furnace collapsed the water was very low at the time.

The water level is generally shown in a glass tube called a gauge-glass. It is essential that the water in these gauges be protected from the agitation caused by ebullition; that it be free from suspended matter, which might be deposited on the surface of the glass; lastly, that the temperature be kept down, in order to avoid their breaking, owing to the cold currents of air in the stokehold. To ensure these conditions the gauge-glass is fixed, not to the boiler itself, but on a brass column called the gauge-column, standing quite clear of the boiler, to which it is attached, and with which it communicates by two copper tubes of considerable length, the top one going to the steam space, the lower one to the water space. These two pipes are fitted with cocks or valves. The gauge-column sometimes has two gauge-glasses of different lengths (Fig. 205).

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The glass tube fits into brass sockets communicating through two cocks with the gauge-column. The handles of these cocks, which are connected by a rod, are so arranged that they cannot close automatically, and have to be raised to shut them. The upper end has a screw-plug for inserting the glass tube and a

ORDINARY GAUGE-GLASS.

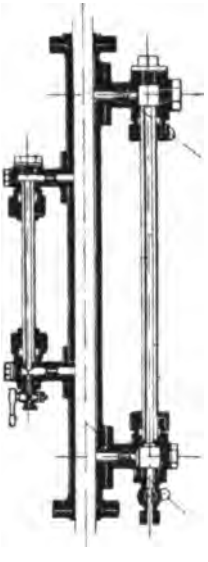

Fig. 205.

LOUPPE GAUGE-GLASS.

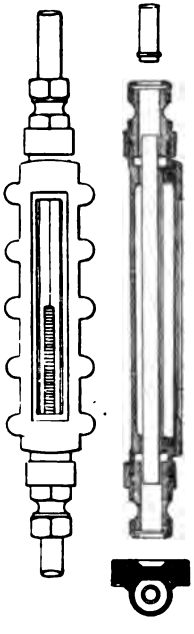

Fig. 206.

HOPKINSON'S AUTOMATIC WATER-GAUGE.

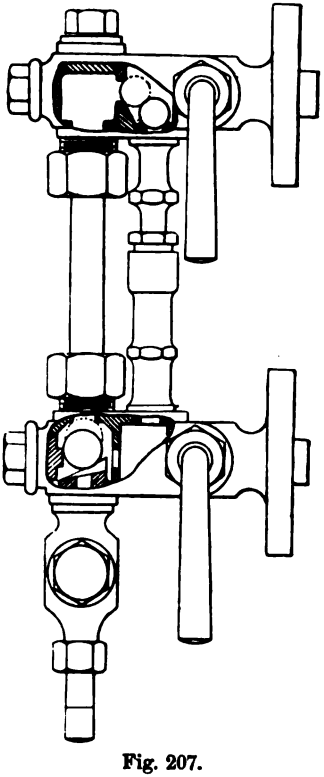

Fig. 207.

drain-cock is fitted at the bottom; two small stuffing-boxes, one at each end of the glass tube, complete the apparatus.

Care must be taken that the tubes and passages are all kept clean and clear, and engineers should be drilled to shut the cocks as sharply as possible when a glass breaks and so prevent the filling of the boiler-room with steam and the consequent

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panic which so often occurs, especially amongst inexperienced stokers.

There are two ways of preventing the dangers arising from a broken glass, one is to protect it by a cover, the other is to make the apparatus self-closing. An example of a protected glass is shown in Fig. 206, this being the Louppe system, in which the water level is seen through a second glass cover. An example of a self-closing apparatus is given in Fig. 207—a design in which the passages are closed by balls driven on to their seats by the sudden rush of water. In the first system it is difficult to see the water, and in the second there is always the fear of the passages becoming blocked. Up to the present time no device has been designed which can be said to give complete satisfaction.

The water level in the gauge-glass is not the same as that of the boilers: there are several reasons for this difference.

In the first place, the water in the gauge-column and its connections is colder, and consequently more dense, than that in the boiler. For a difference of 180° Fahr. the density of the water in the gauge-glass is 1·045 times that in the boiler; this in 6·56 ft. may therefore make a difference of 3½ ins. in the level, that in the gauge being the lower. Although the difference of temperature would probably not amount to 180° Fahr., nevertheless it is not advisable to reduce the height of the column of water below 6½ ft.

In the second place, if the density of the water in the boiler is high owing to condensation, the gauges are continually being replenished with pure or fresh water, and there is a tendency to a condition of things the inverse of the preceding one. For instance, if, while the water in the boiler marked 2° on the salinometer, the external water were quite pure, the ratio of the specific gravities would be 1·000 to 1·052; consequently, for a column 6·56 ft. high the level shown in the gauge-glass would be 4 ins. too high. Tubulous boilers are almost free from this defect owing to the purity of the water it is necessary to use in them.

These two causes of error, of opposite effects, in the indication of the water level are the only ones to which tubular boilers are

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exposed. The amount of error can always be determined by using the gauge-cocks. In tubulous boilers, where there is a rapid circulation, a much more serious cause of error arises, due to the differences of pressure existing in the boiler balancing the inertia of the columns of water in motion. It is this action in the Belleville boiler by which, as the proportion of steam increases and the upward velocity is accelerated, the pressure in the lower drums is increased and is indicated by a rise of water in the gauge-glass of 4 ins. or even of 8 ins. above that in the boiler. In the D'Allest boilers there is, in addition, a deformation of the surface of the water which causes the indications of even the gauge-cocks to be inaccurate (see Fig. 130).

The gauge-cocks, principally intended as checks on the water-gauges, are three in number, and are fixed to the front of the boiler; one is at the normal water level, the second 4 ins. below, and the third 4 ins. above this level. They are easily kept in order, and never deceive an experienced hand: to the novice they appear to invariably eject nothing but steam.

The lower gauge-cock can also be used for drawing off water for testing the density of the water in the boiler.

Fusible plugs have been fitted to indicate when plates become overheated, but they are not in general use in the French Navy. The fusion of a plug is a very serious matter, as the damage cannot be made good without drawing the fires; and where one boiler only is employed, the safety of the vessel itself might, under certain circumstances, be jeopardised by the action of this "safety" device.

It has been shown (Section 110) that fusible plugs were used for a time on the D'Allest boilers; none, however, were fixed on the boilers of the *Jauréguiberry*, where, however, the overheating, which caused the bursting of a tube, would probably not have fused the plugs.

The warning or alarm whistle, actuated by a float, has never been applied to marine boilers.

174. *Feed-water Inlet.—Hand Check-valves.*—The method of introducing the feed water into the boiler is an important matter. By forcing the water into the steam, in the form of a fine spray,

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the air is got rid of, and salts, such as sulphate of lime, insoluble at high temperatures, are immediately precipitated; on the other hand, by introducing it in a body into the water, useful currents may be set up, or existing currents be assisted. For cylindrical boilers, the first method is adopted in the French Navy; the second, in the American Navy. Amongst tubulous boilers, the first method obtains in the Belleville; the second, in the Normand boilers. It is imperative that the feed water be delivered in the main drum, in those tubulous boilers where there is a main drum common to several furnaces, in order to simplify, as far as possible, the feed pipe and the regulating of feed check-valves.

On the front of the boiler, close to the feed-water inlet, is placed the apparatus for regulating the level of the water.

The level of the water is always regulated by simply altering the section of the inlet; should the pumps deliver too much water, the excess is returned to the hot well or feed-tank.

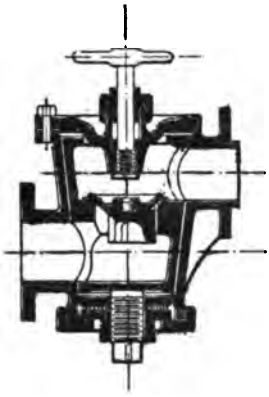

Fig. 208.

The feed supply is generally regulated by a so-called feed check-valve, which is raised by the water on entering, but does not allow it to return. The section of the inlet is increased or diminished by raising or lowering a hand-screw, to regulate the lift of the valve. The type adopted as a hand feed-check is the one known as the "Indret" model. In this, the valve is placed in the plug of a tap or cock, as shown in Fig. 208. By closing the tap the valve is cut off from the boiler, and can therefore be detached for inspection and cleaning.

A certain amount of regulation by hand is always necessary when several boilers are fed by one pump or from one common feed-pipe. In fact, if there exist slight differences of pressure in several of the boilers—as often happens—the valves will open widest at the boilers where the pressure is least, and will remain closed at the other; but it may so happen that while the water is

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low in all the boilers most water may be needed in the boiler having the greatest pressure.

175. *Automatic Feed-water Regulators.*—The adjustment of the feed is very much facilitated where the regulating valve is actuated by a float. This arrangement is more particularly of use on tubulous boilers, where the slightest delay in the admission of the feed may cause a dangerous drop in the level of the water in the boiler. It is also to be recommended on large vessels, where attention has to be divided amongst a large number of tubulous boilers.

BELLEVILLE AUTOMATIC FEED REGULATOR.

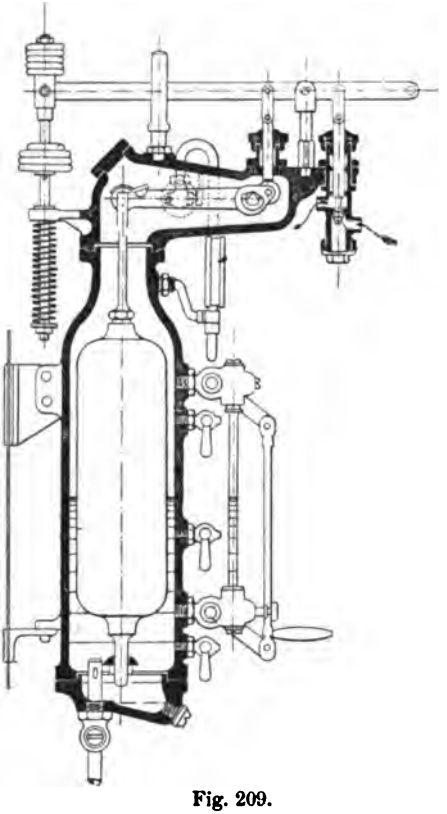

Fig. 209.

Automatic regulators were introduced into the French Navy by M. Belleville. Fig. 209 shows the design now in use on his boilers, which has varied but little since its first introduction. The valve is controlled by a lever acted on by two opposite forces, the one a spring tending to shut it, the other a float which opens it as the water level falls. A special rod works the lever to allow of opening by hand, independently of the float. The vessel in which the float works is placed on the column leading the water from the separator to the feed collector.

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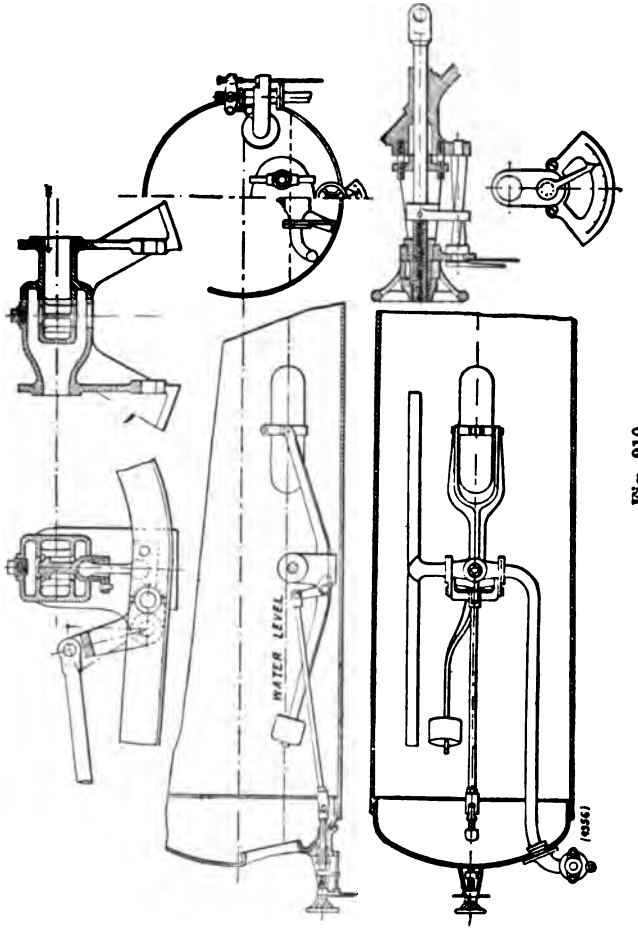
A great number of various designs of automatic feed regulators have been brought out owing to the development of tubulous boilers.

Mr. Thornycroft places his regulator inside the boiler.



THORNYCROFT AUTOMATIC FEED REGULATOR.

Fig. 210.

It is composed of a float, partly balanced by a counterpoise, which actuates a double-seated valve by means of a lever and link. Regulation by hand is accomplished in a simple manner by adjusting the vertical position of the pivot about which the

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float lever turns. As the parts moved by the float do not pass through stuffing boxes, the variable friction due to this cause is eliminated, and the gear is consequently very reliable.

Figs. 211, 211A, and 211B, show examples of two other designs, one with a plug, the other with a slide valve. They are not novel in principle, but have been designed by M. Sigaudy for the boilers of the *Jeanne d'Arc*.

In Fig. 211, which has a plug, the hand regulator is worked

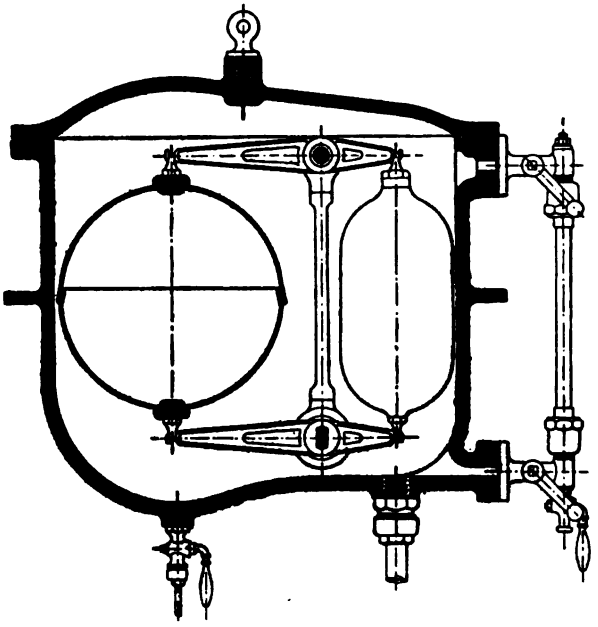

Fig. 211.

by altering the opening by means of a sleeve working on the outside of the plug actuated by the float (Fig. 211A).

In the design with a slide valve (Fig. 211B), all that is needed is to alter the length of the slide rod.

M. Messier has contrived a highly original arrangement (Fig. 212) in which the regulator is actuated by a diaphragm ; the upper surface of this diaphragm is under a constant pressure, while the pressure on the under side of it is increased by the weight of the column of water H, when the level of the water

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in the boiler gets below the opening of the long tube at the normal level.

M. Normand has recently fitted to some of the French torpedo-boats in which there are only two boilers, a very simple arrangement to reduce the care and attention necessary in supervising the feed. He connects the upper steam drums with one another, below the water level, by means of a pipe of large diameter, as also the two bottom water drums. This enables a free circulation of water to take place between the two boilers, which are separated by the stoke-hold floor, only one feed supply for two boilers being necessary, and it eliminates any differences there may be in the rate of working of the boilers. Thus the total water passing through the engine is returned to the boilers, without any supervision as to the quantity going to each boiler being necessary.

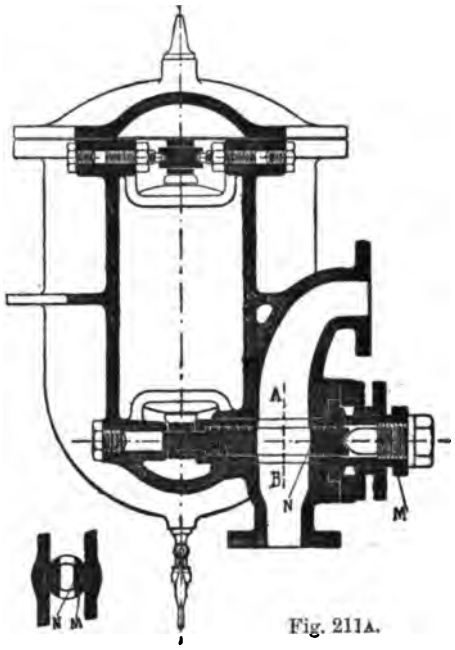

Fig. 211A.

Section on A B.

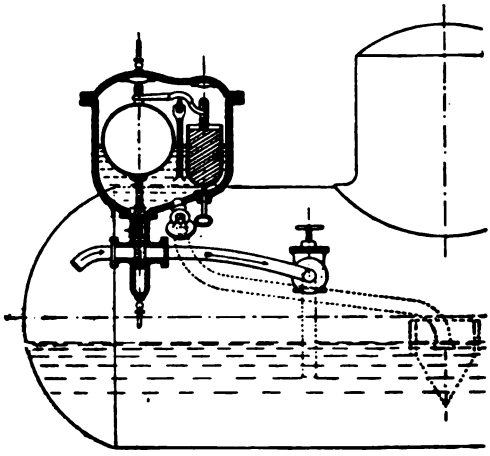

Fig. 211B.

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Mr. Yarrow has also introduced a feed regulating apparatus of somewhat original design. He connects the steam pipe of the feed donkey pump direct to the top drum of his boiler in such a way that its inlet is just above the normal water level,

MESSIER'S AUTOMATIC FEED REGULATOR.

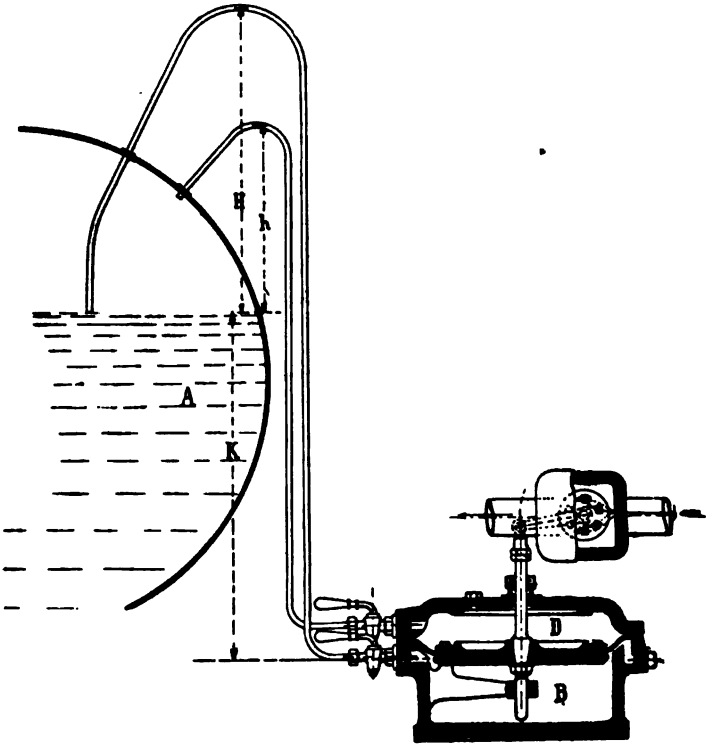

Fig. 212.

A. Boiler at working pressure P.
B. Receiver at pressures $\begin{cases} P + K, \\ P + K + H. \end{cases}$
D. Receiver at constant pressure P + K + h.

and can be varied at will (Fig. 212A). If the water is below the inlet, steam passes to the steam cylinder of the donkey pump in the usual way, and water is forced into the boiler at a high velocity. This raises the water level and causes the orifice of the internal steam pipe to take water instead of steam, thereby slowing down the engine. It continues to work slowly, extracting the sur-

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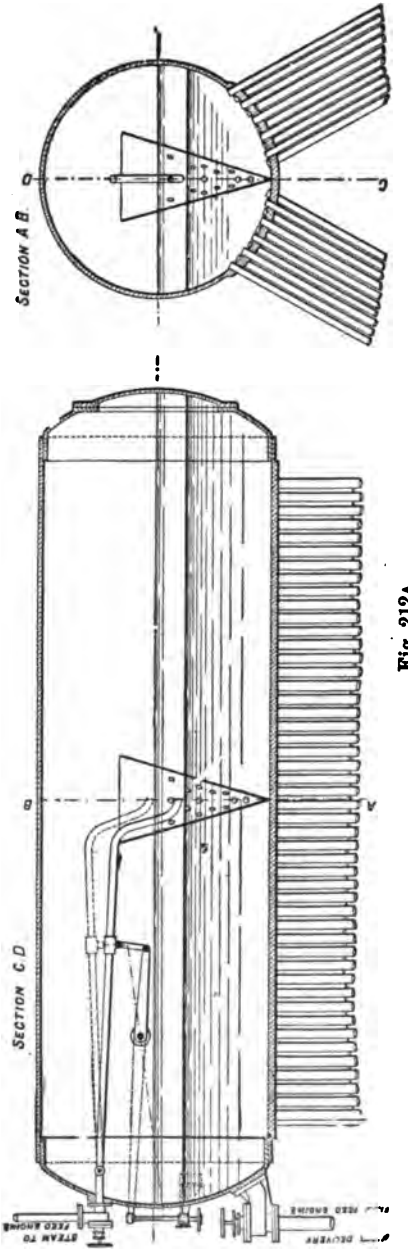
plus water from the boiler, due to the difference between the capacities of the steam and water cylinders, until the water in the boiler is brought down to the normal water level. This system not only raises the water level if too low, but automatically reduces it if too high. The exhaust from the steam cylinder is led to the feed suction pipe and goes to heat up the feed water when steam is passing through the cylinder; should the cylinder be working hydraulically the hot water is simply taken from the boiler through the steam cylinder and passed to the condenser through an escape valve. This system, though involving a slight loss of heat, has the advantage of mechanical simplicity.



YARROW'S AUTOMATIC FEED AS APPLIED TO THE YARROW WATER-TUBE BOILER.

Fig. 212A.

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176. *Saturation and Salinometers.—Continuous Blow-off.* When a boiler is fed with water loaded with salts, these latter are concentrated by distillation. The water in the boiler soon becomes very highly saturated, and it becomes necessary to blow off a quantity of this highly saturated water, containing an amount of salt equal to that brought in by the feed water.

The density is determined by taking the specific gravity of the water at 203° with a little hydrometer called a salinometer. This instrument is so graduated that it indicates 0° in fresh water, 1° in sea water, and then as many degrees as the water contains multiples of the quantity of salt in sea water.

When boilers were fed with sea water the saturation was kept at 3° by a constant blow-off through a pipe fitted with a cock; the opening of this cock was regulated according to the amount of saturation recorded from time to time. The resultant loss of heat by this constant blowing off came to about 12 per cent. of the total amount given to the boilers, when the saturation was kept down to 3°; the loss would still have been 9·5 per cent. had the saturation been 4°.

When boilers were fed with fresh water and losses were made good with sea water a saturation of 4° was allowed.

177. *Scum, Blow-off, and Blow-down Cocks.*—As at the present time both feed and "make up" with sea water are prohibited, the extraction of sea salt has lost most of its importance. On the other hand, great attention is being paid, and justly so, to the clearing boilers of all mineral oil which may have been brought in by the steam, and which at first floats on the surface of the water. Water instead of being blown off from the bottom of the boiler, as formerly, is now blown off from the surface.

Scum or surface blow-off must take place exactly from the surface, and this is arranged by attaching the end of the blow-off pipe to a float. Fig. 213 shows an apparatus constructed on this principle, and tried on the *Hâleur* at Brest. The blow-off from the surface should be all but continuous, for, as has been

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pointed out in Section 49, the oil does not float long and is soon precipitated.

Floating apparatus are only applicable to cylindrical boilers. For tubulous boilers several kinds of "boiler cleaners" have been invented in England and in America; but the only way to keep oil out of boilers appears to be to purify the feed water, as will be described further on.

As there is always a liability of sea water finding its way into marine boilers, due to leaks in condensers, distillers, etc., a blow-off is always fixed to the bottom of the boilers. Where boilers are fitted with settling drums the blow-off cock is naturally fitted to these.

All boilers have at their lowest point a cock through which they can be completely emptied. For the sake of cleanliness the water from the boiler should not be drained into the bilges, but, as far as possible, into the sea. Any small quantity of water that may be left is drained into a tank and pumped out.

HÂLEUR.

SURFACE BLOW-OFF.

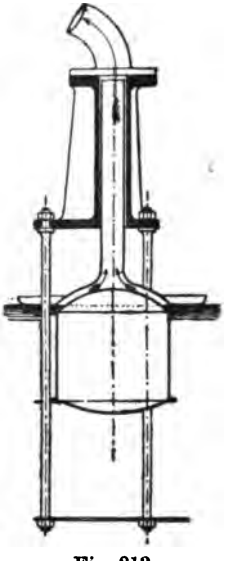

Fig. 213.

178. *Apparatus for Artificially Circulating the Water in the Boiler.*—It has already been pointed out that the shells of boilers are subjected to fatigue during the operation of getting up steam, due to the differences of temperature arising from the stagnation of the water at the bottom of the boiler. The absence of any motion in the water is all the more unfavourable to the diffusion of heat since this takes place by convection and not by conduction. Consequently many devices have been thought of to mechanically stir the water.

The first devices tried were the "Hydrokineters," a kind of Friedman injector in which jets of steam driven along a conical nozzle draw in the surrounding water; the artificial current thus set up is so directed as to carry the cold water

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from the bottom up into the more heated parts. That these hydrokineters are efficient there is no doubt, but their action is very slow. On board a liner, where steam was raised in the careful and cautious manner usual on large merchant vessels, it was found that, four hours after lighting up, the temperature of the water at the surface was 205°, while at the bottom it was only 73°. After a hydrokineter had been fixed, under the same conditions, and in the same length of time, the

WEIR'S HYDROKINETER.

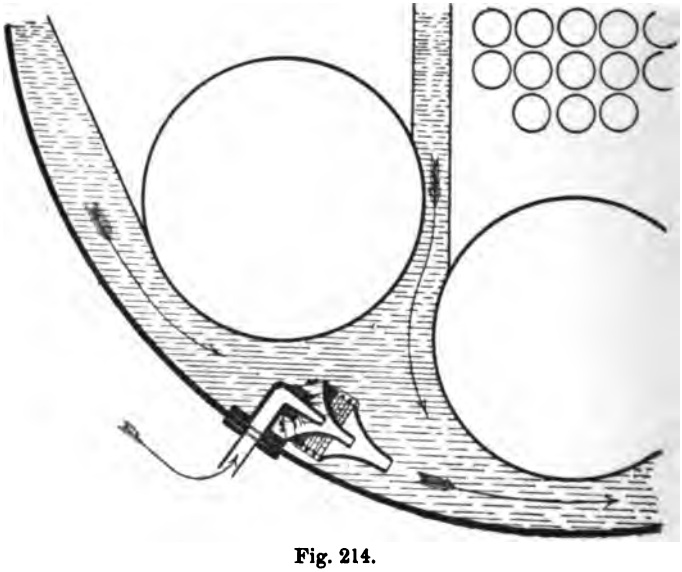

Fig. 214.

temperatures were respectively 205° and 144°; it took six hours more before the temperature was equalised throughout. Hydrokineters, it will be seen, do not answer to the exigencies of vessels of war, where the time taken to raise steam is of great importance. The hydrokineter has two other drawbacks; it necessitates an auxiliary boiler under pressure and it ceases to act when the temperature and pressure of steam in the main boiler has reached that of the auxiliary boiler.

In the American Navy the steam jet has been replaced by a jet of feed water forced through a conical nozzle. The arrange-

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ment answers well as long as the boiler is at work, but when at rest and raising steam the injector is of no use, that is to say, it is inoperative just at the time when it is most needed.

ARRANGEMENT USED FOR CIRCULATING THE WATER IN THE BOILER BY MEANS OF THE FEED WATER.

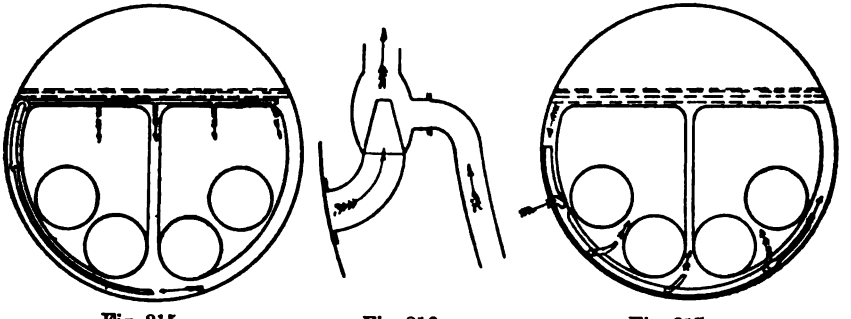

Fig. 215. Fig. 216. Fig. 217.

The circulators used at Indret by M. Garnier are thoroughly efficient. They consist of small centrifugal pumps, fixed out-

ISLY.

CENTRIFUGAL PUMP FOR CIRCULATING WATER IN BOILER.

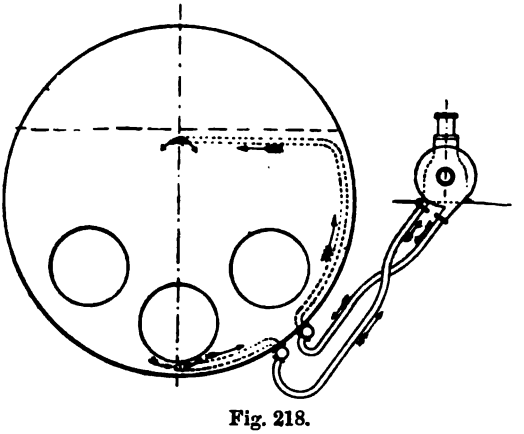

Fig. 218.

side the boilers, which take water from the bottom and discharge it a little below the water level. The pumps are turned by hand while raising the pressure, and are worked by steam

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when sufficient pressure has been raised. A small 1½ I.HP. engine is sufficient to give vigorous circulation in a boiler with two or three furnaces. The efficiency of these circulators has been well established, both as regards the absence of fatigue of the shell during lighting up and the production of steam while under way. It has also been noticed that they prevent overheating of furnace crowns and leaky tube-plates. This apparatus is now in general use on cylindrical boilers.

179. *Water Purifiers.*—Both the water in boilers and the feed water contain marine salts, fatty acids resulting from the decomposition of tallow (where this is used in the stuffing-boxes), mineral oil and air, all of which are harmful, as has been shown.

The marine salts are removable through the blow-off at the bottom of the boiler, as described above; the salts of lime are immediately precipitated on their arrival in the boiler, when the feed water is fed into the steam space. It only remains to describe the apparatus designed to extract or neutralise the other substances contained in the feed water. Steam feed-water heaters (described in Section 183), which in the first instance were fitted solely with a view to economy, were found to possess certain properties very useful in the purification of water, that is to say, where the heating is done through a surface and not by mixing. The surfaces of such heaters rapidly become coated with grease and require to be frequently cleaned; whatever is got rid of in this way is so much gain to the boiler. And further, any air taken up by the water after leaving the condenser is set free in the heaters, where it is discharged through cocks provided for that purpose.

The problem of extracting the fatty acids has never been satisfactorily solved. When, some twenty years ago, it was first attempted to get rid of these acids by the help of lime, a special apparatus was designed by M. Risbec for automatically injecting into the boiler a fixed proportion of lime. This has been officially adopted in the French Navy. At first the apparatus consisted of two force pumps, and was rather complicated. In Fig. 219 is shown a form of it very much simplified, which was designed

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in 1880 by M. Dudebout. The mixing of the lime and water

DUDEBOUT'S FEED-WATER PURIFIER.

Section on E F G H.

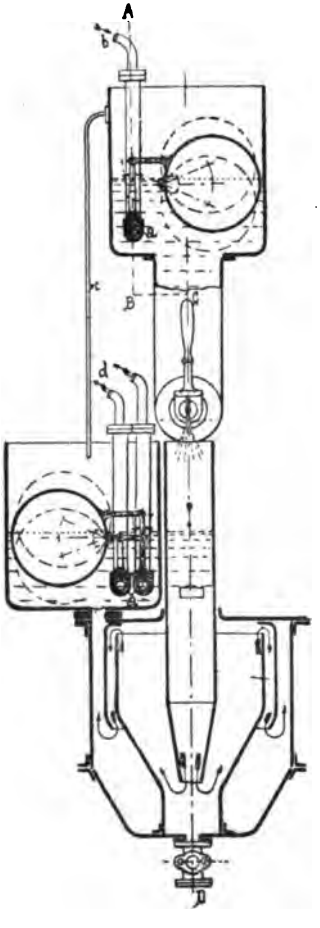

Fig. 219.

Section on A B C D.

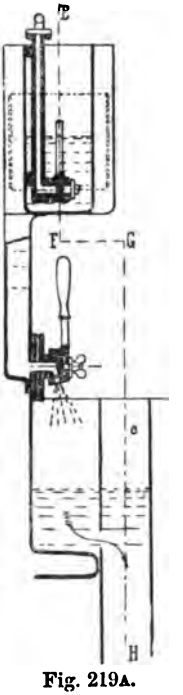

Fig. 219A.

DETAILS OF COCK *a*.

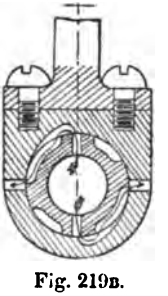

Fig. 219B.

a. Water inlet controlled by float.
b. Pipe from feed discharge.
c. Overflow pipe.
d. Suction pipe to condenser.
e. Pipe for introduction of powdered lime.

is effected at the bottom of a chamber placed about half-way

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up the apparatus. The water, coming from a reservoir in which a constant level is maintained, is admitted through cocks worked by hand. The powdered lime is introduced through the tube *c*. The stirring is effected in the lower chamber by causing the water to circulate round the baffles shown in the figure. The mixture then passes into a reservoir from which it is blown direct into the condenser. In this last reservoir a constant level is automatically maintained in order to prevent air entering the condenser. The figure shows a form of the apparatus suitable for two condensers. The whole work consists in pouring lime and water into the mixing chamber.

Lime water is always used for filling up tubulous boilers when laid by, and is also often employed in ordinary working when a simple mixing vessel is used connected with the hot well. The use of alkaline carbonates has been entirely abandoned, as mentioned in Section 76. With the exception of lime, which, when used under steam is not without its drawbacks, all addition is avoided, and rightly too, of any new chemical substances to those, already too numerous, contained in the feed water.

180. *Zinc Plates.*—The principal chemical, or rather electro-chemical agent, actually employed as a preventative of corrosion consists of zinc plates suspended inside the boilers as near to the feed water inlet as possible, except when this is in the steam space.

The effect of the zinc is to neutralise the free acids in the water by combining with them; it takes the place of iron in causing the precipitation of salts of copper when present, and finally, and above all, it produces a galvanic effect, keeping the iron in an electro-negative state, thus rendering it but little liable to oxidation.

In order to bring about the desired galvanic action, a simple voltaic cell is formed; the zinc plates are attached to the iron to be protected, by strips of copper, care being taken that contact is established between perfectly clean surfaces. All direct contact between zinc and iron must be carefully avoided; it is even advisable to provide means for catching such pieces

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of the attacked metal as may become detached. The recognised proportion between the surfaces of zinc and iron is 0·015 to 1·000, which means placing as much as 180 to 220 lbs. of zinc per furnace in cylindrical boilers.

Zinc plates are sometimes placed in the hot wells, feed-tanks, etc., not so much to preserve their surfaces as to commence the process of the neutralisation of the water.

These zinc plates have been called by Hannay and others "electrogenes." Zinc has been credited with the property of rendering boiler deposits less hard and adherent.

Fig. 220.

181. *The Extraction of Mineral Oils from Feed Water. — Sponge Filters.*—To solve the difficult problem of getting rid of the mineral oil before the feed water reaches the boiler, it is necessary to have recourse to mechanical means, for no known chemical agent is capable of absorbing and precipitating the oil.

An apparatus applicable to engines of all sizes, is the sponge filter (Fig. 221). The feed water is made to pass through it after leaving the air-pump, the feed-pump suctions being placed at the bottom of the filter.

NORMAND SPONGE FILTER.

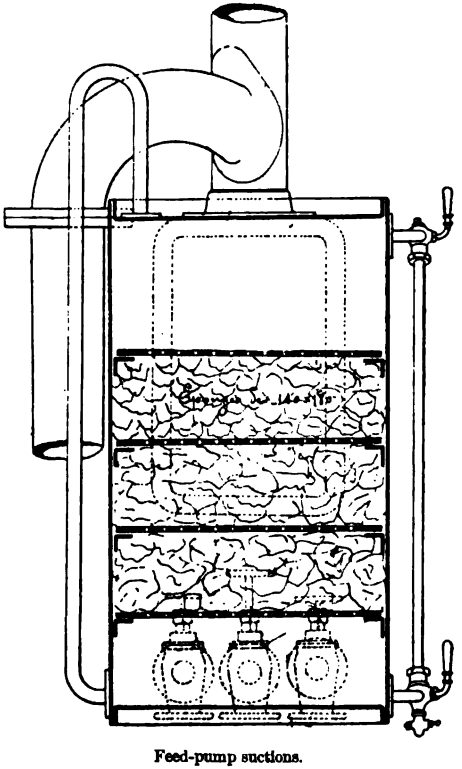

Fig. 221.

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The sponges arrest the mineral oil very well, while allowing the water to pass; they can be used for a considerable time if periodically cleaned with soft soap or caustic potash. The filter is provided with a by-pass, enabling the feed to go on while cleaning is being done.

The sponge filter was used for the first time in France by M. Normand on his torpedo-boats.

The great cost of sponges has caused them to be replaced as filtering material in the large American boats by bundles of hay.

ARRANGEMENT FOR CHANGING SPONGES WITHOUT STOPPING THE FEED.

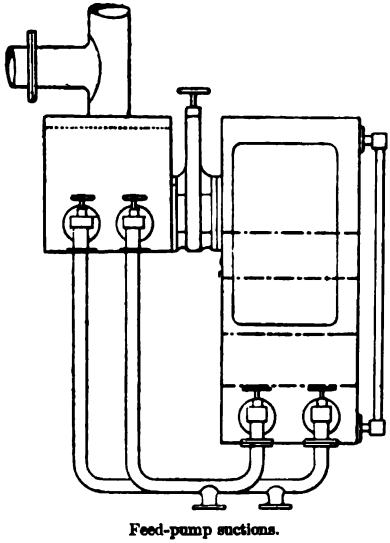

Fig. 222.

In practice the introduction of a filtering apparatus entails a slight modification in the working of the air-pumps. It is therefore advisable, at least on big engines, to place the filter on the discharge side of the air-pump, so as to allow the water to get to the feed-pumps freely. In the Royal Navy preference has been given to filtering the feed water between the feed pump and the boiler and therefore under full boiler pressure. Several different filters of this type are in use, amongst which the Harris, Rankine, and Edmiston may be mentioned.

182. *Extraction of Grease from Steam.*—Various forms of apparatus for getting rid of grease and oil have been patented under the name of "grease extractors" or "oil eliminators"; the only ones of real interest, because they are rational in principle, are those which act on the steam itself in its passage from the cylinder to the condenser.

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The action of steam purifiers is analogous to that of other purifiers in that a curvilinear motion is imparted to the current, arresting the liquid particles due to their inertia. The shape given to the sides is much more complex than in other purifiers. The two Figs. 223 and 224 represent two patterns, the one vertical, the other horizontal, and are sufficiently clear without any further explanation.

These apparatus may be very suitable to certain small vessels,

DE RYCKE'S OIL EXTRACTORS.

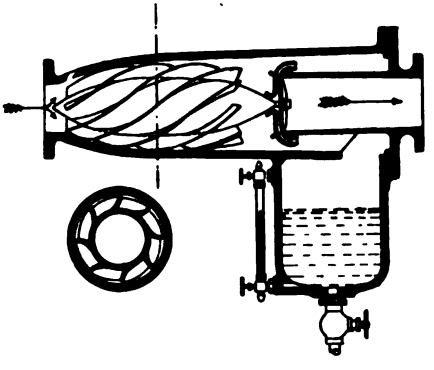

Fig. 223.

Fig. 224.

but on the low-pressure exhaust of a large engine they would have to be of an excessive size.

183. *Feed-water Heaters Heated by Steam.—Calculation of their Theoretical Efficiency.*—Steam feed-water heaters are in reality small condensers, in that steam, that has already done work in one or two cylinders, is employed to heat the feed water instead of sending it into the last cylinder, where only a portion of its heat would be turned into work.

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Heaters, like condensers, may work either on the surface or by mixing, as in the jet condenser. The Normand pattern, shown in Figs. 225, 225A, is a surface-heater. The patterns used in England and in America are either surface-heaters, as in Fig. 226, or injection-heaters, as in Fig. 227.

The surface-heaters are the favourites in France. The reasons for this preference have already been given. Experience has clearly established the utility of steam-heaters, from the point of view of economy. The saving of coal consequent on their adoption has never been less than 10 per cent. when the position of the apparatus was well chosen. The primary cause of this saving, as far as can be shown by calculation, may be thus stated:—

Take the extreme case, from a purely theoretical point of view, of an engine working at a pressure of 284 lbs., and with quadruple expansion, under the following conditions:—

—	Pressure.	Temperature.	Total heat in thermal units of one pound of steam.
	Lbs. per Sq. In.	Degrees.	
Boiler	284	412	1208
First receiver . . .	115	337·9	1185
Second receiver. . .	37	262·3	1162
Third receiver . . .	8·5	185·7	1139
Condenser	1·4	114·2	1116

Assuming the temperature of the feed water before it is heated to be 68°, this would require an application of 1,172 B. T. U. to convert it into steam at a pressure of 284 lbs. per square inch.

With the aid of the exhaust steam we can first heat the water to 114·2° without spoiling the vacuum; in raising a pound of water from 68° to 114·2°

$$\frac{46 \cdot 2}{1116 - 46 \cdot 2} = 0 \cdot 043 \text{ lb. of steam}$$

will be condensed.

The result will be 1·043 lbs. of feed water, presuming the

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SURPRISE.

Normand's Feed-water Heater.

Section on *c d* fig. 225A.

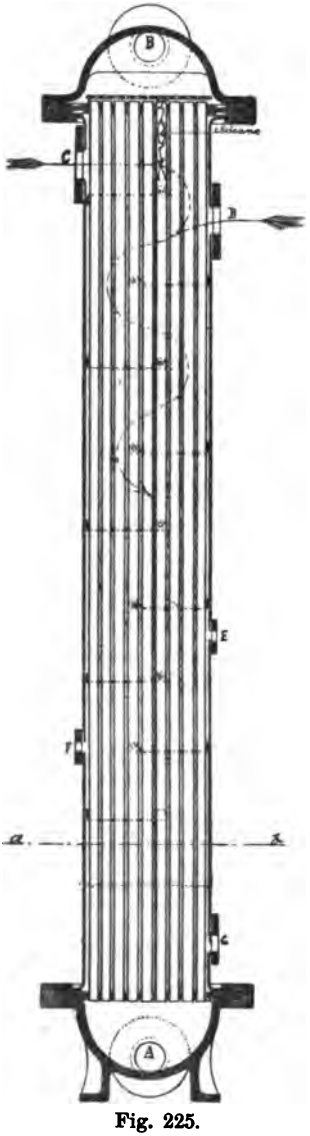


Fig. 225.

A. Feed inlet.
B. Feed outlet.
C. Steam from L.P. casing.
D. Auxiliary exhaust inlet.
E. Equilibrium valve to trap.
F. Air cock.
G. Condensed steam outlet to main condenser.

Wainwright Heater.

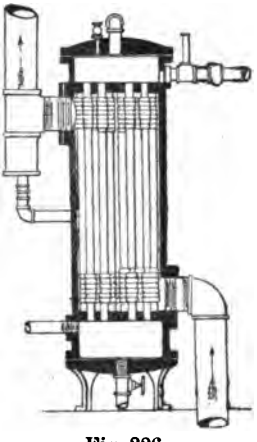


Fig. 226.

Weir's Injection Heater.

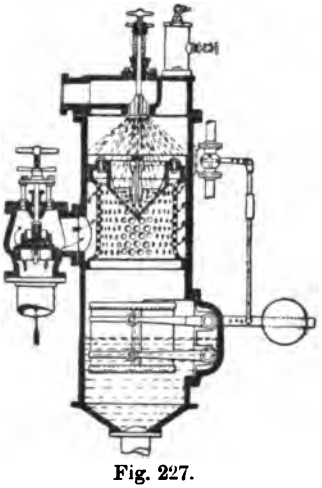
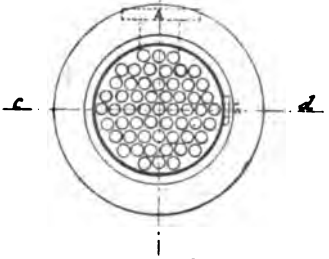


Fig. 227.



Section on *a b* fig. 225.

Fig. 225A.

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heating to be done by injection, or under precisely similar conditions in a surface-heater.

Water raised 71·5° from 114·2° to 185·7° will condense per lb.—

$$\frac{71{\cdot}5}{1139 - 185{\cdot}7} = 0{\cdot}075 \text{ lb.}$$

The pound of water originally at 68° will be thus changed into $1{\cdot}043 \times 1{\cdot}075 = 1{\cdot}125$ lbs. of water at 185·7° which, to be raised to 262·3°, will condense per lb.

$$\frac{76{\cdot}6}{1162 - 262{\cdot}3} = 0{\cdot}085 \text{ lb.}$$

The original pound of water will therefore have become

$$1{\cdot}125 \times 1{\cdot}085 = 1{\cdot}220 \text{ lbs.}$$

Similarly, after heating has been done by steam from the first receiver, the weight of the heated water will have become $1{\cdot}220 \times 1{\cdot}089 = 1{\cdot}328$ lbs.

The water having been thus raised to 337·9° Fahr. will only have to take up

$$1208 - 337{\cdot}9 = 870{\cdot}1 \text{ B.T.U.}$$

in the boiler, the resultant saving having been

$$\frac{1140 - 870{\cdot}1}{1140} = 0{\cdot}24.$$

With respect to this saving of 24 per cent. in the heat to be given to the water, the consequent loss of work per pound of steam remains to be calculated. Presuming that the work is equally divided between the four cylinders, which is sufficiently accurate for all practical purposes, the calculation is easy.

The 1·328 lbs. of steam produced is employed in doing work and in heating feed water:—

(1) $1{\cdot}328 - 1{\cdot}220 = 0{\cdot}108$ lb., performs one quarter of the total work, and is then condensed;

(2) $1{\cdot}220 - 1{\cdot}125 = 0{\cdot}095$ „ performs half the total work;

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(3)	1·125 − 1·043 = 0·082 lb.	performs	three-quarters of the total work;
(4)	0·043	„	performs the whole of the normal work;
(5)	1·000	„	performs the whole of the normal work.
	Total 1·328 lbs.		

The work that would have been performed by the 1·328 lbs. of steam in the four cylinders is

$$\frac{0{\cdot}108 \times 0{\cdot}75 \times 0{\cdot}095 \times 0{\cdot}5 \times 0{\cdot}082 \times 0{\cdot}25}{1{\cdot}328} = 0{\cdot}11.$$

The final result of the net saving is therefore

$$0{\cdot}24 - 0{\cdot}11 = 0{\cdot}13 \text{ or } 13 \text{ per cent.}$$

In practice it has never been proposed to employ four successive heaters. The exhaust steam is not used for fear of air finding its way to the condenser by using a heater which acts practically as a second condenser. Heating is only done once with the steam from one of the receivers.

By a calculation analogous to the above, a theoretical saving of 8 per cent. may be obtained by heating from the third receiver, and of 5 per cent. from the first. In practice it is preferable to use the second receiver; the saving effected depends on the position of the heater, which should preferably be in the engine-room, and close to the point whence it takes its steam.

One of the principal advantages of heating the feed water is that, on introducing the water hot into the boiler, it is in a position to take up the heat from the heating-surface more readily on coming in contact with it. The circulation is then increased and the transmission of heat by convection improved This explains the large saving that has been realised when taking steam from the second casing. There is an economy to be obtained when taking live steam direct from the boiler, but it is not so great as in the previous case.

184. *Apparatus for making good Losses of Fresh Water.—Single Distillers.*—Marine engines cannot be worked without a

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certain loss of fresh water, either continuous, owing to leakages of all kinds, or occasional, owing to draining into the atmosphere, blowing off, etc. The total quantity of water contained in the boiler and in the feed apparatus would therefore be constantly diminishing were not some supplementary agencies occasionally used for making up this loss.

The use of sea water as "make-up" being nowadays forbidden,

DISTILLER ON BOARD GUNBOAT "CROCODILE."

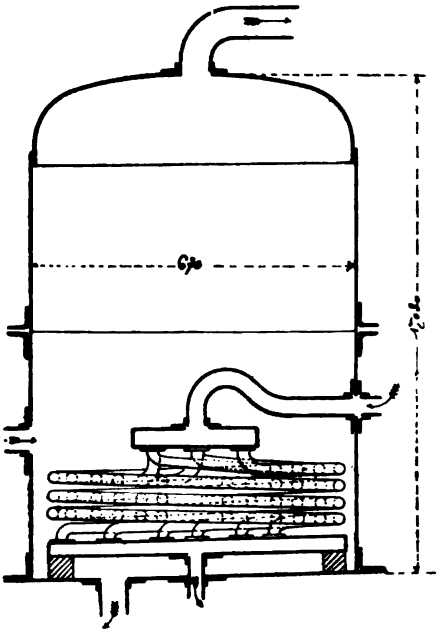

Fig. 228.

it is necessary to have either a reserve quantity of fresh water or an apparatus used for producing fresh water known as a "distiller," or "evaporator."

Distillers have been in use on board ship for many years. They were formerly solely employed in providing the fresh water required by the crew. These have simply been enlarged so as to cope with the new requirements of the engines.

For producing drinking water, separate condensers are pro-

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vided; for feed water, the main condensers of the engines are used.

For a long time steam was produced in boilers fired with coal and fed with sea water, working at a low pressure and constantly blown off. As it was soon found impossible to make room for these auxiliary boilers on small boats, the steam from the main boilers was brought into use for heating purposes. The first distillers were simply cylindrical chests in which sea water was heated by a steam coil. The steam condensed in the coil was returned to the boilers, and the steam, issuing from the distiller, was condensed for drinking purposes. Fig. 228 is an apparatus of this kind, fixed in 1873 on the gunboat *Crocodile*.

COUSIN DISTILLER.

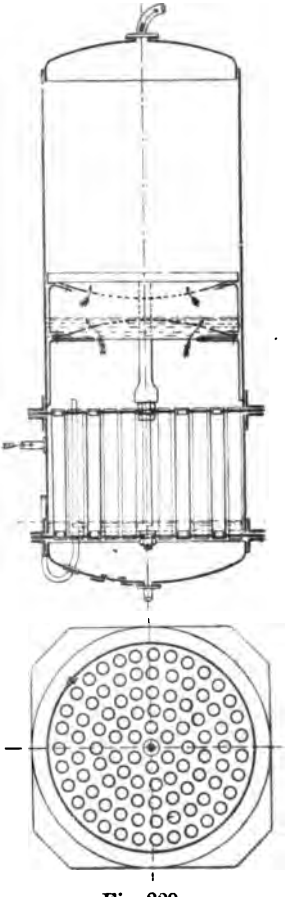

Fig. 229.

The coil was subsequently replaced by a nest of tubes, expanded into two tube-plates and surrounded by steam. Such are the Cousin condensers, named after the engineer who designed them; they are single acting, and are still in use on many vessels. At the present time coils have been reverted to, as they do not give rise to leaky tube-plates. With this apparatus a smaller weight of steam is obtained than in the main boilers whence the steam for condensation is taken, viz., about 6 lbs. of steam in the evaporators per pound of coal burnt in the boilers.

185. *Multiple Distillers.*—In single distillers the heat of the steam produced is entirely lost. In the multiple ones, on the contrary, this steam is utilised, and they are much more economical; they were invented by M. Sochet in 1832.

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The principle of these multiple distillers consists in placing several distillers in series, each one serving as a condenser to the preceding one, and as a heater for the succeeding one. If there were no loss of heat from radiation, all the distillers would produce an equal amount of water, and from an originally limited amount of steam an indefinite amount of fresh water could be obtained. There is no paradox in this principle, as there would be no loss of heat, and there is, further, no work to be done.

However, on account of radiation, the production of steam diminishes, from one distiller to the others, at a certain rate q, equal say to 0·9 or 0·8. Consequently 1 lb. of initial steam produces, in successive distillers, q, q^2, q^3 ... q^n lbs. of steam; the quantity of fresh water obtained over and above the first pound condensed is thus expressed:—

$$q + q^2 \ldots + q^n = q\,\frac{1 - q^n}{1 - q}$$

of which the limit with n infinite would be

$$\frac{q}{1 - q}$$

M. Sochet's first apparatus consisted of six vessels, one being in reserve, out of each of which the condensed water was extracted by a small hand air-pump. At present three vessels are considered sufficient, and the distiller is therefore a triple one, as shown in Fig. 230.

In this apparatus, as constructed by Messrs. Mourraille, the vessel I. takes its steam direct from the main boiler, and heats vessel II., which in its turn heats vessel III. Both the temperature and the pressure naturally diminish from one vessel to the other.

The sea water to be evaporated is first heated in the heater IV. by the water condensed in vessel III. It then passes to distiller III., in which the pressure is sufficiently low to allow of the feed being fed in, merely by the atmospheric pressure and the difference between the sea level and the level of the water in the distiller. Any water that has not been evaporated

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in distiller III. is passed back by a pump to distiller I.; what is left after I. passes into II.; the remainder not evaporated in II. is discharged into the sea.

MOURRAILLE'S TRIPLE DISTILLER.

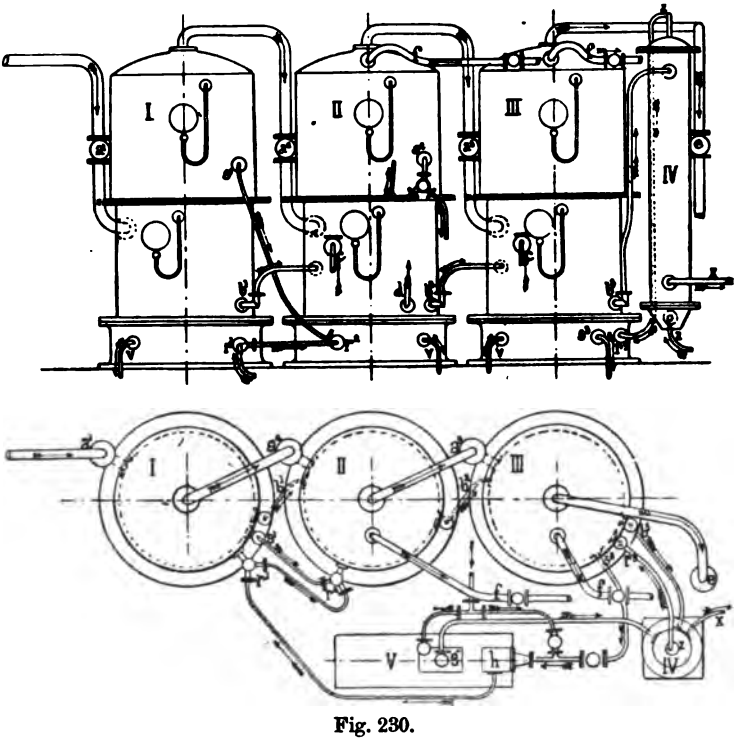

Fig. 230.

I. High pressure distiller.
II. Mean ,, ,,
III. Low ,, ,,
IV. Feed-water heater.
V. Donkey feed.

a^1. Heating steam to distiller I.
a^2. ,, ,, ,, II.
a^3. ,, ,, ,, III.
b^1. Condensed steam outlet of distiller I.
b^2. ,, ,, ,, ,, II.
b^3. ,, ,, ,, ,, III.
c. Auxiliary steam.
d. ,, blow-off.
e. Exhaust to condenser.
f. Steam ,,
g. To cold-water pump.
h. To hot-water pump.
r^1. Water inlet to distiller I.
r^2. ,, ,, ,, II.
r^3. ,, ,, ,, III.
s^1. Blow-off of distiller I.
s^2. ,, ,, ,, II.
s^3. ,, ,, ,, III.
v. Drain-cock.
x. Water to hot well.
z. Inlet and outlet of feed water to heater.

The water condensed in I. is not fit for anything but the feed make-up; it is generally run into the condenser, where it makes up for the loss of steam in the distiller.

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The steam produced in the three vessels, if required to make good any waste, is also usually sent back to the condenser; a better plan is to avoid losing the benefit of its heat in this way, and to take it back to the intermediate casing, where it will easily find admittance on account of its higher pressure. This point will be dealt with in the next section.

The Mourraille distillers are constructed with either tubes or coils. The interior arrangement of coil distillers is given in Fig. 231. This reminds one forcibly of the first distiller constructed by M. Bigot, at Cherbourg. The heating is effected by a coil, through which steam circulates in the centre of the liquid to be vaporised. There are no tube-plate joints. The interior is easily cleaned by taking off the bottom, which is removable.

Mourraille Coil Distiller.

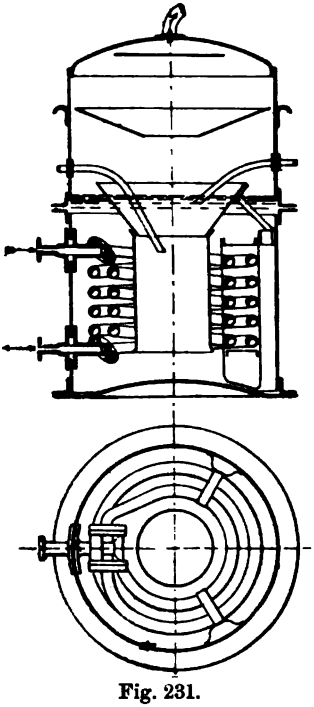

Fig. 231.

Single distillers of various sizes and of similar design have been constructed, principally for use on torpedo-boats, and they work satisfactorily. The only fault to be found with them is their weight, which is excessive. M. Oriolle has, however, constructed some which, while exactly similar in their action, are much lighter.

The production of fresh water, and, in consequence, the economical yield of the triple distillers, is just about three times that of single ones. Experiments made on the *Jean-Bart* and on the *Brennus* have actually resulted in a production of 17 lbs. of fresh water per pound of coal burnt.

The principal data relative to the Mourraille and to some other types of distillers, as well as their total yield of fresh water per 24 hours, are given in the following Table:—

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		Total Heating Surface.	Weight of Apparatus, Exclusive of Water.	Yield of Water per 24 hours.
		Sq. Ft.	Tons.	Lbs.
Mourraille distillers.	Triple tubular distillers . . . Large size	678·15	5·766	13,228
	Medium „	452·10	4·162	8,818
	Small „	226·04	2·656	4,409
	Single tubular distillers (Cousin type) . . . Large „	107·64	1·377	33,069
	Medium „	64·58	0·984	19,841
	Small „	24·76	0·639	7,716
	Single coil distillers . . . Large „	78·04	1·156	24,251
	Medium „	43·06	0·875	13,228
	Small „	7·00	0·069	2,205
	Triple Oriolle distiller	1,324·00	2·789	132,276
	Single Weir distillers . . . Large size	114·10	..	55,115
	Medium „	78·9	..	39,683
	Small „	49·94	..	24,251

The considerable variations in the heating surfaces, and in the weight, of apparatus similar in principle and of similar yield, tend to show that a standard and definite type is still a long way off.

The rule followed as to the output of the distillers in ships of the French Navy is that 9,000 lbs. a day are to be the output for every 1,000 maximum HP., with a fresh-water reserve of 4,500 lbs. per 1,000 HP. This allows, if the engines consume 13 lbs. of steam per horse-power hour, $\frac{1}{36}$ of the steam to be lost without drawing upon the reserve, and to work, when using reserve and all, either for twenty-four hours with $\frac{1}{24}$ of the steam, or for twelve hours with $\frac{1}{18}$ of the steam, and at full speed in every case.

The loss of steam from the main engine, when in charge of a careful engineer, is very slight indeed, in some cases practically nothing at all; but in all auxiliary engines, in consequence of long steam-pipes without steam-traps, the loss of fresh water is, generally speaking, very considerable.

186. *Distillers, yielding both Fresh Water and Useful Work.*—The question of distillers is of interest apart from the losses of

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fresh water in the engines and boilers, however great we may suppose these to be, and also apart from the production of fresh water for the crew. Steam in the form of jets may at times be put to important uses, such as it may not be called upon to perform under ordinary circumstances. The great obstacle in the way of thus employing the steam is the cost of the fuel in making good the loss of fresh water, as has already been shown in Sections 36 and 37 with regard to forced draught, and in Section 50 in the spraying of petroleum. It has been shown in Sections 36 and 59 that, according to the method employed in making use of the steam, the cost of make-up more than doubles the cost of fuel. This estimate is too low in the case of the single distillers, which are those most often met with on modern ships. In reality the cost is multiplied by 2·5, for the fuel consumed gives only two-thirds of the amount of steam which it would have given had the water been evaporated in the main boiler.

In the triple distiller, while the cost of working has to be multiplied by only 1·5, it gives three times the output. This cost is still too high, and further, in order to yield the quantity of fresh water which a forced or induced draught may require, the weight of the triple distillers, under existing circumstances, becomes excessive.

It is therefore of vital importance to increase the present output, with the ability to vary it in quantity according to requirements, while keeping the weight of the apparatus within reasonable limits.

M. Gayde, during a trip with a naval squadron, thoroughly investigated the question of losses of fresh water, and of the means for preventing them. As the result, he advocates an arrangement of distillers which would reduce the cost of production of fresh water.

The principle thus advocated is to employ the steam in a single distiller in such a manner as not to lower its temperature to the point of condensation, and, at the same time, to employ the steam thus produced in doing some useful work in the engine instead of evaporating more fresh water. The original steam, partly lowered in temperature, and the steam raised in

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the distiller, both having the same, or practically the same pressure, would be returned to one of the receivers of the engine, having a pressure equal to their own. Their evaporative efficiency per square foot of heating-surface depends on the pressure existing in the receiver. Further, the two steams from the distillers can be used in different ways. Theoretically, the total loss of heat might be reduced in this manner to zero, or rather to the simple loss by radiation and conduction of the distiller and piping. The distillers might, indeed, be easily so arranged as to give, if required, a large output at any time when a great quantity of fresh water happened to be required at short notice.

This combination of producing steam and doing useful work is worthy of trial. Mr. Weir has made an application of the principle by using steam which has already done work, or given out some of its heat in the engine, to heat his distiller, and passing the steam produced into the low-pressure casing.

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CHAPTER XIX.

ACCESSORIES RELATING TO THE DISPOSAL OF ASHES.

187. *The Handling of Coal and Ashes.*—There are as yet no mechanical appliances for handling coal on board worth noticing. A system of coal buckets and of mechanical firing was put in operation some time ago, but it was soon given up and has not again been brought into use. The introduction of briquettes has very much facilitated the handling of fuel, not only in the bunkers, but even in the stokehold. The clearing away of the ashes is, on the other hand, a most important operation for which the old hand or steam winch, awkward and noisy, is now considered unsatisfactory.

188. *The De Maupeou Ash-hoist.*—This apparatus has been designed especially for use under forced draught with closed stokeholds, where it is difficult to raise the ash-skips, as they have to be passed through air-locks.

The way the difficulty is got over is by grinding the ashes, mixing them with water, and ejecting them into the sea by means of a force pump.

The apparatus has been modified from time to time, and now consists of two jaws, one fixed, the other movable, between which are passed the ashes to be ground. The fixed jaw, supported on a strong spring, yields slightly should a piece of iron pass through with the ashes. Any damage from this cause is thus avoided, and the regular working of the apparatus is ensured.

The result of an experiment made at Cherbourg in 1887 with the De Maupeou ash-hoist, showed that, with a lift of

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17 ft., it ejected a weight of $\frac{3}{4}$ lb. of ashes per second. The power absorbed by the grinder and the pump amounted to 2,170 ft.-lbs. The machine has, as would be expected, an

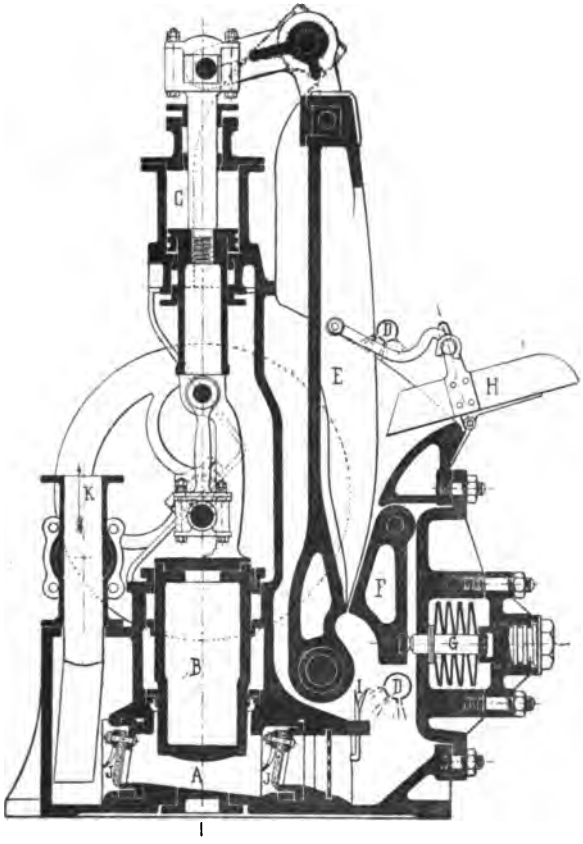

Fig. 232.

A. Body of the pump.
B. Ash-piston.
C. Steam cylinder.
D. Water-pipe.
E. Movable jaw.
F. Fixed jaw, supported by
G. Spring.
H. Rocking-table for receiving ashes.
I. Comb to catch waste.
J. Indiarubber valves.
K. Ashes discharge pipe.

exceedingly small mechanical efficiency, but in these matters steady and easy working is of greater importance than high efficiency.

189. *Water Ash-ejectors.*—Both ashes and clinker may be

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discharged into the sea, without any grinding, by means of water-ejectors, of which there are several kinds.

In the ejector used on the American ferry-boats, the ashes are first mixed with water in a long vessel into which sea water is admitted through a tap. The ejector-pipe, which withdraws the mixture from the bottom of the vessel, has a jet of water under pressure delivered in the direction of its longitudinal axis by one of the force-pumps on board.

In the See or Trewent ejector (Fig. 233), tried in 1896 at Cherbourg, the dry ashes are tipped directly into the ejector through a hopper. The water jet, with a pressure of from 170 to 260 lbs., is delivered through a tapering nozzle. Small clack valves allow air to enter the ejector-pipe above the nozzle.

See Ash Ejector.

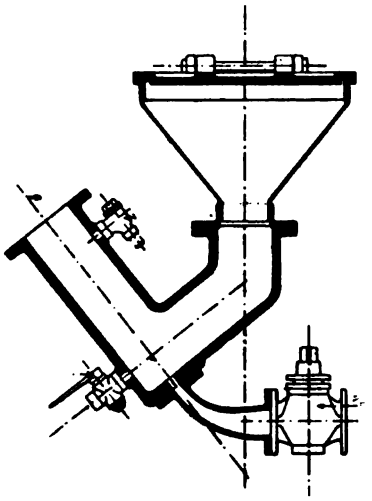

Fig. 233.

With a lift of 18 ft., the apparatus tried delivered 6·4 lbs. of ashes per second, with an expenditure of 3,655 ft.-lbs. on the pump pistons. The mechanical efficiency was therefore equal to 3 per cent. The average discharge for lifts of 18, 22·8 and 27·56 ft., was found to be 9·84, 8·36 and 4·92 tons an hour, the necessary water pressure being 170·8, 206 and 241·7 lbs. per square inch respectively. Trifling difficulties occurred which appeared to be easily avoidable.

The See ejector has the further advantage over the grinding ejector, that it is much simpler in construction and in action, besides being four times as effective. Its output is considerable, and allows of very rapid working. It has done good

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service on the steamers of the Compagnie Transatlantique, and is to be tried on the *Bouvet* and the *Du Chayla*.

A steam ash-ejector was worked for some time on board the *Corse;* it worked well, but its output was very small. The necessity for economising fresh water acts as a bar at present to the use of steam-ejectors.

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